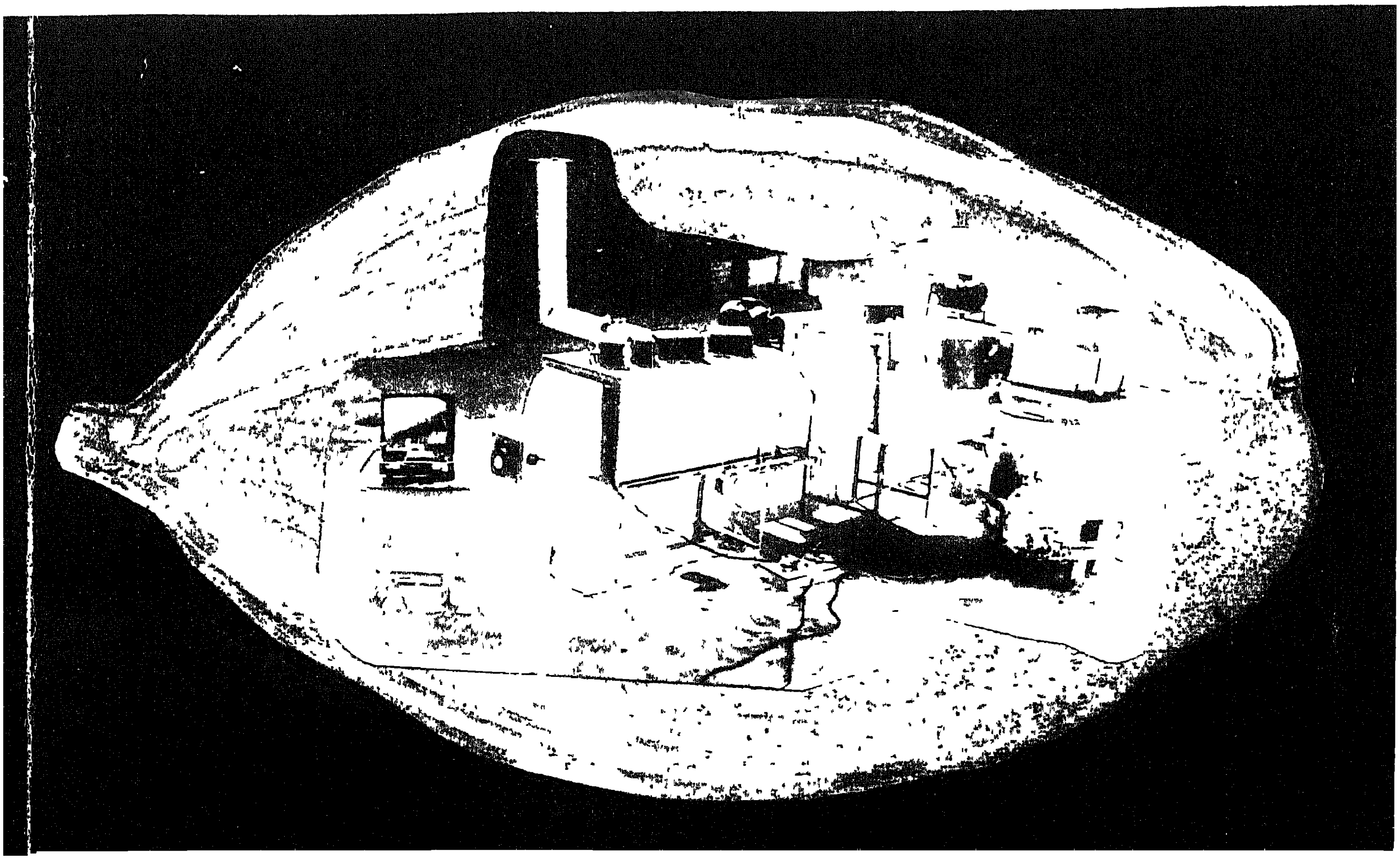
DESIGN, FABRICATION, TESTING AND FIELD DEMONSTRATION OF ENERGY EFFICIENT DRYER FOR SOME CASH CROPS

FINAL REPORT

Submitted to

Department of Science and Technology
Technology Bhawan, New Mehrauli Road
New Delhi - 110 016



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TATA ENERGY RESEARCH INSTITUTE
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By

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7, Jor Bagh, NEW DELHI - 110 003.
(1991)

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1. INTRODUCTION

In the original proposal [1] of the project submitted to DST in 1986, the following objectives were spelt out.

Main Objectives:

- To survey the present curing methods of selected cash crops to find ways and means of improving the overall efficiency of the drying system.
- Design, fabrication and testing of proto-type drying unit consisting of (i) improved furnace, (ii) efficient plate-fin type heat exchanger, (iii) cabinet tray dryer and (iv) blower in such a way to optimise the overall thermal efficiency of the system and to reduce the drying time.
- Field testing of the system for few cash crops to test the viability of such devices.
- To study the possibility of making the system independent of electrical power supply.

All the above objectives have been achieved. The findings of the investigations carried out in the project are discussed in the following chapters.

2. SURVEY OF PRESENT CASH CROP DRYING SYSTEMS

The first step in improving any system is to study the existing system and collect the preliminary data. In this regard many cardamom stores, coffee curing yards, tobacco barns, cashew and tea processing factories in South India were surveyed under this project. The objective of this survey was to get preliminary information about different aspects of drying such as fuel consumption, method of drying i.e. type of heat exchanger used, drying time, etc. for a few cash crops. This helps in identifying one particular representative cash crop which can be studied extensively and main bottleneck of its poor thermal performance can be found out which in turn helps in developing more efficient drying unit. The same can then be used for other crops with appropriate modification i.e. after tuning the system as per requirement of that particular crop. A list of plant estates and research institutes visited is enclosed in Annexure - I. A crop-wise description of the processes involved is given in the following sections.

2.1 Cardamom

Cardamom (Elettaria Cardamomum Maton) know as 'Queen of Spices" is a native of Southern Western mountains of the Indian peninsula. The cardamom belongs to the natural order of the Scitamine and the family of Zingiberaceae to which ginger and turmeric also belong. Cardamom is grown abundantly in the lush green forests of Western ghats touching the states of Kerala, Karnataka and Tamil Nadu. The crop is concentrated in Iddukki, Palghat and Kozhikode districts of Kerala; Coorge, Hassan and

Chikamagalur districts of Karnataka; Madurai, Tirunelveli and Coimbatore districts of Tamil Nadu. At present Kerala occupies 60% of the estimated area and 74% of production of cardamom in India [2]. The current world production of cardamom is estimated to be about 7,700 M.T., shared by India (57%), Guatemala (33%), Tanzania (6%) and Sri Lanka (4%) [3]. Fig. 2.1 shows India's production and export earnings from cardamom.

There is also another variety of cardamom known as Ammomum Subalatum or large cardamom. It is cultivated in Sikkim, West Bengal and Assam in the Himalayan and sub-himalayan regions.

Cardamom is mainly a small farmer's business having 84% of planters with less than 4 ha. of land but 5% of planters own 41% of the total area (Table 2.1). Thus these are plantations dominated by small farmers in number and by large farmers in area. Productive plantations range in size from small areas well under 0.5 ha. to very large estates of over 200 ha. [4].

The cardamom picking season generally begins in the month of August and extends upto January to March depending upon rains. In the picking season 5 to 6 rounds of plucking will be done. The amount of collection in each round increases and peaks at the middle of the season and declines at the end. Each round of picking will continue for 2 to 3 weeks with an interval of 2 to 3 weeks between successive rounds which generally depends upon climatic conditions.

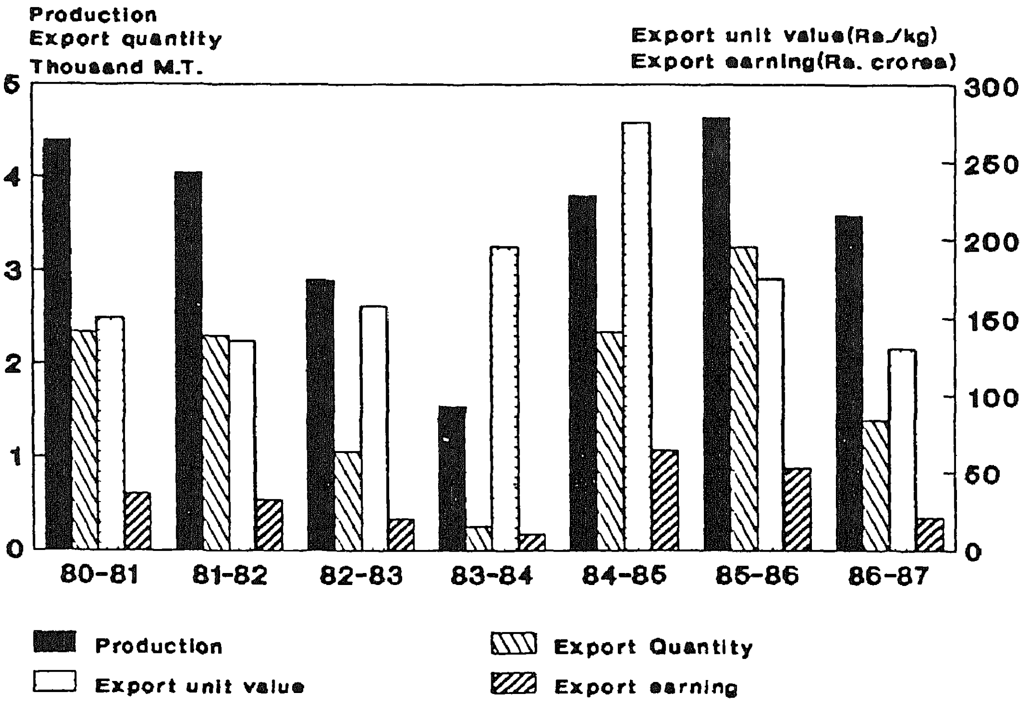

Fig. 2.1 India's production and export of cardamom

Table 2.1: Cardamom estates - analysis by size

Size of holding ha.	Number of estates	Total No %	Area ha.	Total hectarage %
0-2	17,190	65.9	16,104	19.4
2-4	4,717	18.1	13,029	15.4
4-8	2,612	10.0	14,135	17.0
8-12	1,114	4.3	13,023	15.7
12-40	252	1.0	6,248	7.8
40-80	117	0.4	6,711	8.1
80-200	67	0.3	8,211	9.9
above 200	12	+	5,323	6.4
Total	26,081	100.0	82,964	100.0

+ Less than 0.1 per cent

Fresh cardamom has a moisture content of about 80% (w.b.) which has to be reduced to about 10% (w.b.). The fresh green cardamom must be properly dried in order to bring out the aromatic flavour and for longer preservation. Sundrying is not allowed as it bleaches the green colour of cardamom which is economically appealing. The quality of the cured cardamom is determined by its green colour and size (which varies from 8.5 mm bold variety to 4 mm pan variety). This colour will be retained only with proper curing while driving out the moisture. The majority of the cardamom is still cured by a time old, inefficient and uneconomical process in cardamom curing chamber locally called as "Cardamom Stores".

The general principle of this curing chamber is that of space heating with a heat exchanger. Hot flue gas, obtained by the combustion of the fuel wood with air in an oven (see Fig. 2.2), is passed through metal pipes, laid inside the curing chamber and air surrounding the flue pipe gets heated up and rises to the top of the curing chamber by natural convection (See Fig. 2.3). The fresh cardamom is spread in mono-layer on wire mesh racks inside the curing chambers. Generally 30-36 hrs. are required to dry the cardamom to an acceptable moisture content level. The conventional cardamom curing chambers generally operate with very low overall efficiency of about 3-8%. The design and dimensions of these curing chambers have wide variations. There are two categories of the cardamom stores in operation.

The first type (fuel efficiency 2% and below) consists of a single room without any upper storey. The oven is usually kept outside the chamber and the hot flue gas pipe from the oven passes through the room and then outside. There is no provision to remove the moist air. At the end of the 2nd or 3rd hour of curing operation, the windows are opened to remove the excess moisture. The chamber contains no insulation.

The second type of curing chamber consists of a ground floor where oven (in some cases outside) and display of hot flue gas pipe are situated and one or two upper storeys in which cardamom are spread in mono-layer on the ground, formed by wooden rafter and wire mesh, and vertical wire mesh racks.

The opening of windows after 2nd or 3rd hour to remove moisture is adopted. Most of the existing curing chambers fall under this category (fuel efficiency 3-8%). In some curing

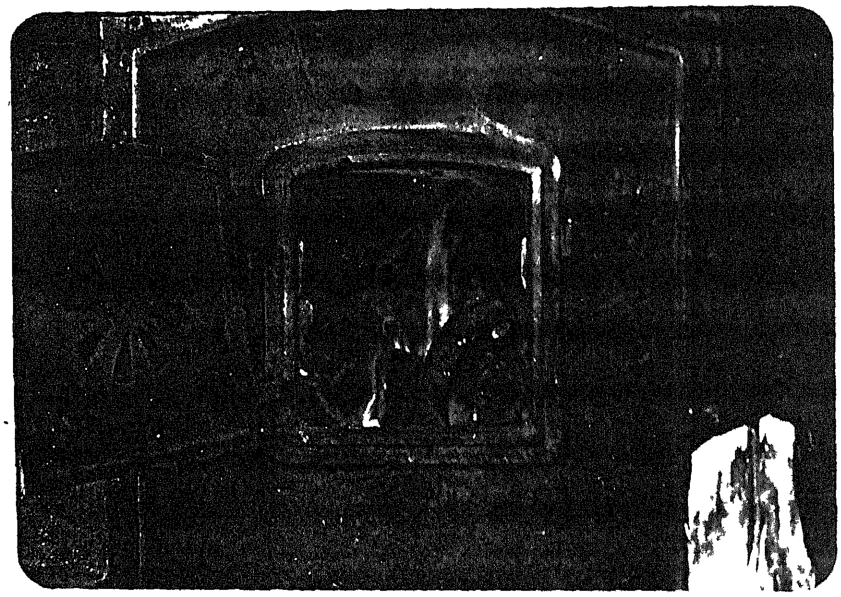

Fig. 2.2 Furnace of conventional cardamom curing chamber

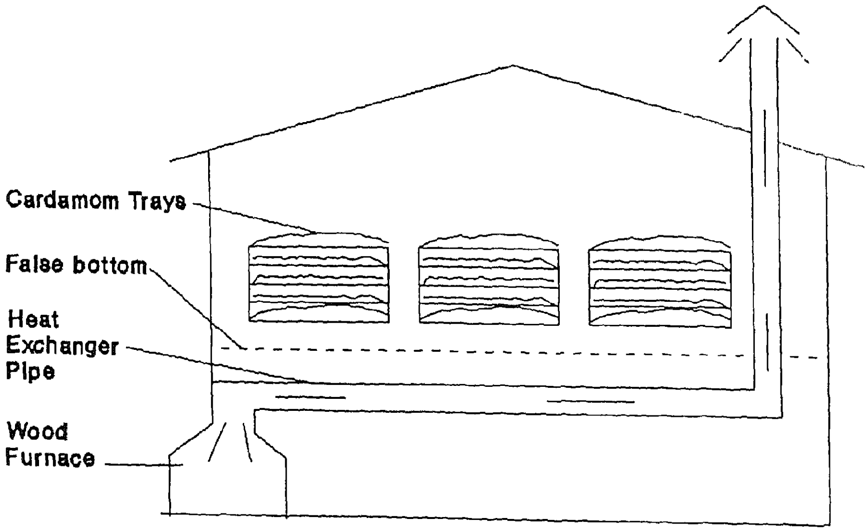

Fig. 2.3 Schematic diagram of cardamom curing chamber

chambers exhaust fan is provided at the top to remove moist air during initial period of drying.

Generally the temperatures inside the curing chamber are maintained at 40^{o}-45^{o}C for the initial 8 hrs, 45^{o}-50^{o}C for the next 10 hrs, and 50-55^{o}C for rest of the time. The fuel used for cardamom curing is firewood and about 3 to 4 kg of firewood is required to dry 1 kg of green cardamom. On an average 0.23 to 0.25 kg of dry cardamom is obtained from 1 kg of green cardamom.

Many research institutes such as Regional Research Laboratory (RRL), Central Plantation Crop Research Institute (CPCRI), Indian Cardamom Research Institute (ICRI) etc. have developed different cardamom dryers. These were tested at ICRI, Myladumpara in order to have preliminary data on their performance for further modifications. The details of the tests carried out by ICRI are given in Table 2.2 [5].

From the observation of these performance test data on different cardamom dryers it can be concluded that there is still lot of scope for improving thermal efficiency and reducing drying time in a cardamom curing process.

In the hilly regions such as Kumuli hills in Kerala where production of cardamom is a major activity, the availability of coal and electricity is a severe problem. Since the cost of coal at the site is very high and electricity supply is not regular, all the planters are using firewood as a source of energy for drying of cardamom. Nowadays planters are facing severe shortage of firewood due to fast depletion of forests and due to forest

Table 2.2: Performance data of the various cardamom dryers tested

Name of the dryer	Capacity in kg	No of trials carried out	Temp. maintained (^{o}C)	Qty. of dry cardamom (kg) mean	Percentage recovery	Drying time (mean) hrs.	Fuel type	Qty used (kg)	Colour of dried caps
1. Low cost dryer (CPCRI)	30	2	40-55	5.150	17.17	32	Firewood	31	Faded gr
2. MELCCARD	120	2	40-60	23.275	19.40	26	- do -	215	Green
3. Electrical dryer (RRL)	55 (chemically treated)	2	45-60	10.850	19.73	22	Electricity	18.5* units/ hour	Green
4. Electrical dryer (Mercara)	30	3	45-50	Could not complete due to power failure					

* Approximate consumption

conservation acts imposed by the Government. A field survey of plantations showed that the planters are becoming aware of the fact regarding the shortage of firewood and hence they feel that there is a need to develop fuel efficient drying systems.

2.2 Cashew

Cashew cultivation is an important horticultural activity in India. Cashew (Anacardium occi-dentale) was introduced in India by early Portuguese settlers in the 16th century. It later spread as a dryland crop in Kerala, Karnataka and Goa. After independence, cashew cultivation has caught the fancy of agriculturists in Maharashtra, Tamil Nadu, Andhra Pradesh, Orissa and, to some extent, in West Bengal and Tripura.

In 1989, the total harvest of raw cashewnuts exceeded 2.5 lakh tonnes in the country. This has resulted in a record export of 44,857 tonnes of kernels, valued at Rs. 360.34 crores. Figure 2.4 shows quantity and earnings from export of cashew from India [6].

The cashew industry in India comprises units in the tiny sector and in the small sector. It has a total installed capacity exceeding six lakh tonnes per annum. It is mainly concentrated in Quilon district and some other places in Kerala, South Kanara in Karnataka, Goa, Sindhdurg and Rantnagiri districts in Maharashtra, Kanyakumari and South Arcot districts in Tamil Nadu and Srikakulam district in Andhra Pradesh.

Cashewnuts, after collecting from the trees undergo processing in order to get the finished product, or to extract cashew oil, which is a versatile chemical input for use in the friction-dust, paints and varnishes, foundry chemicals and resin industry. Cashew processing consists of following stages:

(a) Drying and Storing
(b) Roasting
(c) Shelling
(d) Hot (Drying) Chamber (Borma)
(e) Peeling
(f) Grading
(g) Packing

(a) Drying and Storing

The raw cashewnuts purchased from the market normally have moisture. To remove the moisture content, they are to be sun dried in an open yard. After drying, they are stored in bags of

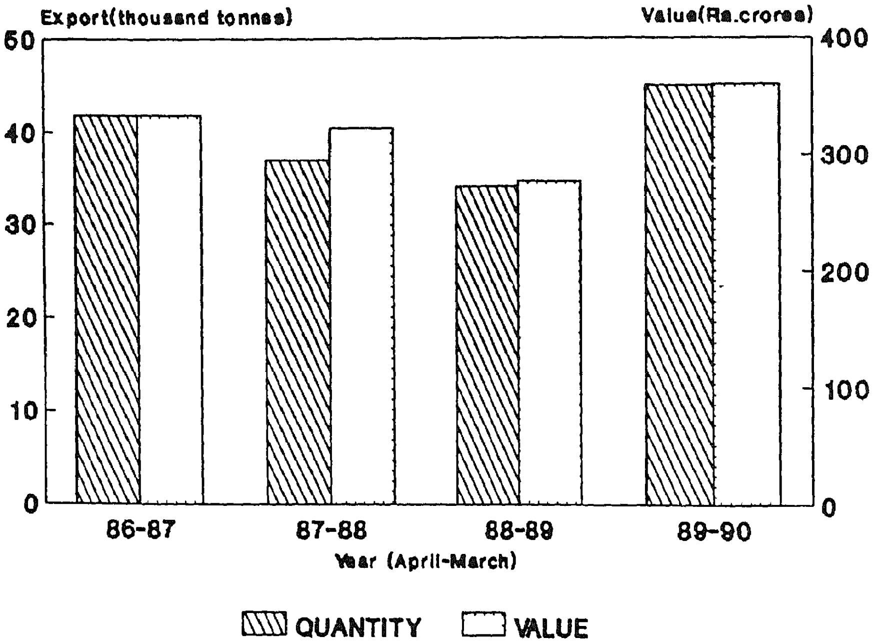

Fig. 2.4 Cashew Export from India

75 kgs. For good keeping quality and for yielding good quality kernel, it is essential that the nuts are dried, though no specific optimum moisture content has been arrived at. With a good drying, they not only stand well, but also give a fairly good product.

(b) Roasting

Roasting involves application of heat to the rawnuts in order to release the liquid in the 'Pericarp', so that the shell becomes brittle and facilitates the extraction of kernel.

In practice, four different methods of roasting are followed:

(i) Drum Roasting

In this process, the nuts are fed into a rotating drum, which is heated initially to red hot sufficiently to allow the shell portion of the nut to ignite and burn (See Fig. 2.5). Once ignition starts, no further heating is necessary and the drum maintains the temperature of its own because of the burning of oil oozing out of the nuts. The temperature of the drum is fairly high. It is stated that in this method of roasting, the shell becomes very brittle and the rate of shelling and the out-turn of whole kernel is higher compared to other methods. The roasting generally takes about 3-5 minutes and the drum is rotated by hand. The roasted nuts which are still burning are removed from the discharge end and immediately covered by ash to absorb the oil that is found on the surface. The chief disadvantage of this method of roasting is the total loss of shell liquid, which has a good commercial value nowadays.

Fig. 2.5 Cashew drum roaster

(ii) Oil Bath Roasting

In this process, the nuts after conditioning are allowed to pass through a bath of heated cashew shell liquid maintained at a temperature of approximately 350-450^{o}F for about 1-2 minutes. The roaster consists of a rectangular vessel with or without a semi-circular bottom, in which there is either a screw or belt conveyor, operating inside the bath of liquid. The vessel is embedded in brick work and heated by a furnace in which spent shell is used as fuel. By adjusting the speed of the conveyor it is possible to adjust the roasting time. It is estimated that more than 50-60% of the shell liquid is released by this means. The nuts are then conveyed by through a suitable outlet to a centrifuge, where the residual oil adhering to the surface of the shell is removed by centrifuging. The nuts are then mixed with ash and sent for shelling. The oil overflowing from the roaster and the oil recovered in the centrifuges are both conveyed to tank for being filled into drums.

(iii) Mild Roasting

The nuts after conditioning are given a mild roasting in equipment at comparatively low temperatures for 20-25 minutes to remove the surface water but not sufficient to bring out the shell liquid. It is said that this process loosens the kernels inside and makes it easy for cutting and removal of kernel. The nuts after roasting are spread on floor in a thin layer for cooling for 24 hours and later they are sent for shelling.

(iv) Steam Roasting

Steam roasting process is now gaining importance in view of the fact that the quality of the cashewnuts is comparatively better and this process requires less labour. It is possible to have better control over the process. Sun dried cashewnuts are put into steam and roasting is carried out for a fixed time. The nuts after roasting are spread on floor on a thin layer for cooling for about 24 hours and later they are sent for shelling.

(c) Shelling

Shelling refers to breaking down of the nut and removing shells. The roasted cashewnuts are cut on the cutters to break open and remove the shells. About 5% of cashewnuts produced in India, principally in Tanjore and South Arcot Districts of Tamil Nadu are simply dried in the sun for 2-3 days and shelled without roasting. Now many factories in Mangalore are using a hand operated deshelling machine which are manufactured locally. This machine is similar to a shear used for supari (arcanut). With the help of this machine it is possible to shell approximately 50 to 55 lbs of nut in a 8 hour day.

(d) Hot (Drying) Chamber (Borma)

As the shelled kernel has a moisture content and is susceptible to fungal attack, drying is to be done immediately. Besides, to facilitate removal of Testa (Red skin), the shelled kernel is heated in a hot chamber (Borma). This shrinks the kernel so that the testa is loosely adhering to it and can be removed by hand. For this purpose most of the factories adopted a tray drier, commonly known as Borma (See Fig. 2.6). They are chambers which are indirectly heated on three sides by means of fuel gases from furnace at the bottom where the shells are burnt. The temperature maintained inside the Borma is of the order of

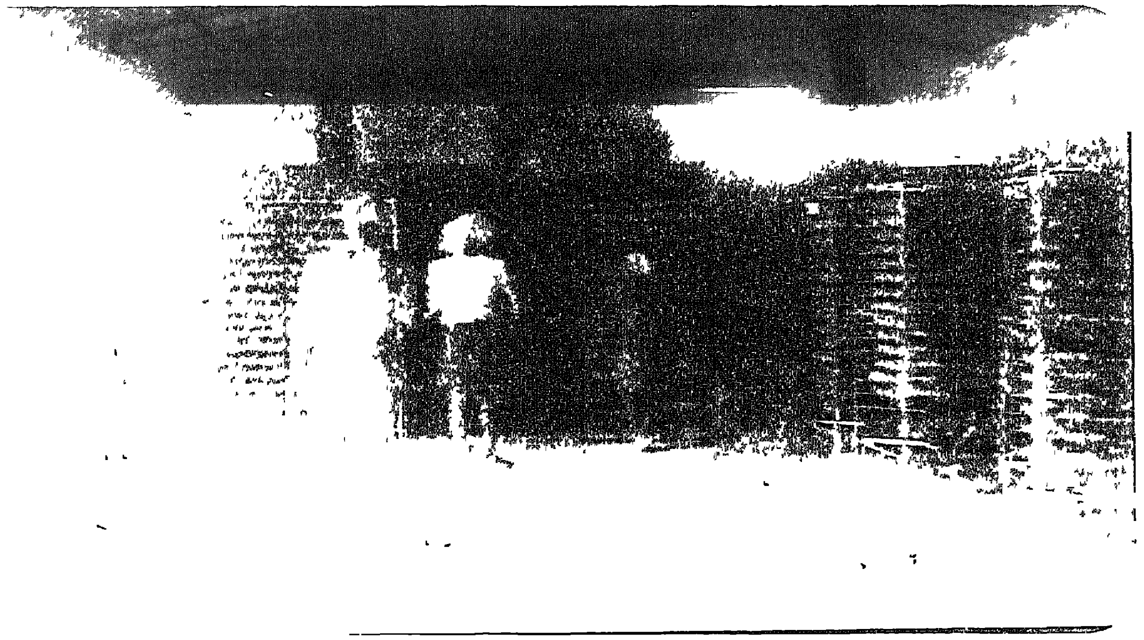

Fig. 2.6 Cashew heating in 'Borma'

80-90°C. The kernels are kept in Borma for periods varying from 3-7 hours and are sometimes interchanged, since there is no uniform heating in all sections of the Borma. After the kernels are heated sufficiently, they are removed from the Borma and heaped in covered metallic wares and kept such for 24-28 hours, before they are sent for peeling.

(e) Peeling

Peeling refers to the removal of Testa (Red skin) of the kernel. This is done by hand. The red skin would have become loose by drying in the Borma and the kernel is easily peeled off.

(f) Grading

After peeling the red skin, the kernels are sorted out into wholes, splits, brokens, etc. and the wholes are graded into different sizes on the basis of the number of wholes per lb., according to the specifications. All these operations are done manually.

It must be mentioned that the cashew kernels derived after the manufacturing process described above are of different sizes and shapes. A high percentage of kernels get broken into various shapes. Also many kernels get scorched or dis-coloured in the process. Therefore, grading is also done according to different sizes, shapes and colours. The kernels ultimately derived from the manufacturing process do not maintain their original shape or colour as naturally existing inside raw cashewnuts. Also, edible cashew kernels in different sizes, shapes and grades of colour are derived from the non-edible raw cashewnuts after the

manufacturing process. The cashew kernels derived are commercially a different commodity than the original raw cashewnuts which are subjected to the manufacturing process.

(g) Packing

Kernels graded are normally packed in 25 lbs tins (11.34 kgs.) which are filled by means of a chute into the tins kept shaken to fill uniformly. After filling and weighing, the tins are vacuumised, and filled with carbon-dioxide gas with the help of gas packing equipment known as 'Vitapack'. Immediately after removal from the 'Vitapack' lids are put on top and soldered.

2.3 Coffee

In India two varieties of coffee are grown viz. Arabica and Robusta. Coffee is grown in South India mainly in Karnataka, Kerala and Tamil Nadu. Table 2.3 gives details of Indian coffee production of each variety, area under cultivation etc. [7].

Both varieties of coffee (Arabica and Robusta) are further divided into two categories viz. cherry and parchment coffee depending upon the method of processing. Cherry coffee is sun dried without removing the outer shell. In case of parchment coffee, firstly the top skin is removed and cherry is washed to remove pulp and then sun dried in the open yard. Figure 2.7 shows a photograph of pulping machine used for removing pulp of parchment coffee cherries.

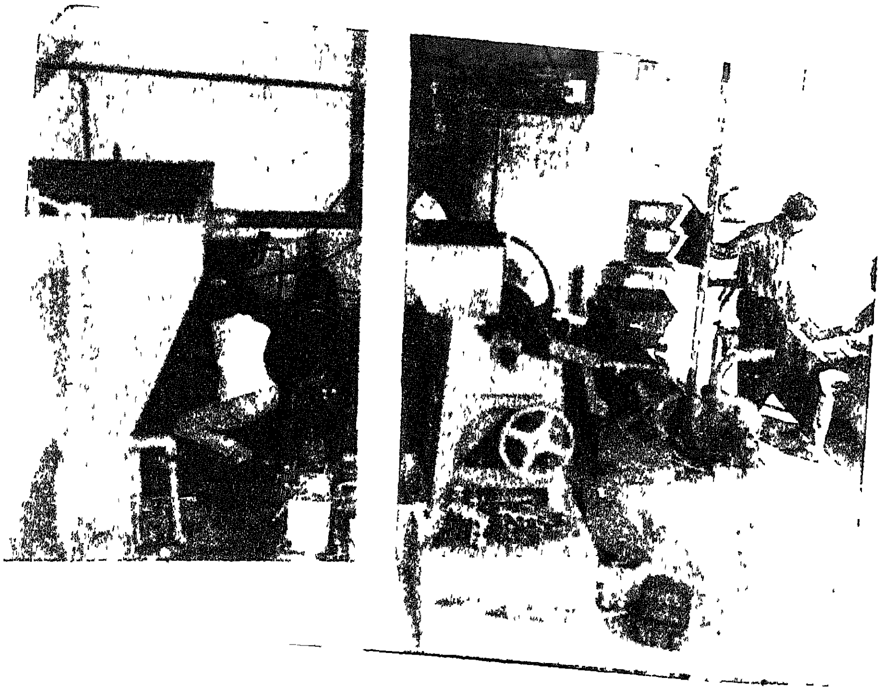

Fig. 2.7 Coffee pulping machine

Table 2.3: Indian coffee at a glance

Major varieties grown :	Arabica and Robusta
Traditional coffee growing: States	Karnataka, Kerala and Tamil Nadu
Coffee season :	October to September

Area under coffee (1987/88 season)	**Arabica** (in Hectares)	**Robusta**	**Total**
STATES			
Karnataka	79,899	46,464	126,363
Kerala	3,190	65,159	68,349
Tamil Nadu	27,270	5,508	32,778
Andhra Pradesh	7,274	--	7,274
Other States	5,682	1,755	7,437
ALL INDIA	123,315	118,886	242,201

India's share in the total world Coffee (1988/89 season)

Area :	2.1 per cent
Production :	3.8 per cent

Size of holdings (31.3.1988)

Size	No. of holdings		Area (Hect.)	
Below 2 Hect.	103,821	(86.6)*	86,652	(35.8)*
Below 4 Hect.	112,607	(93.9)	112,683	(46.5)
Below 10 Hect.	117,790	(98.2)	147,845	(61.0)
Above 10 Hect.	2,150	(1.8)	94,356	(39.0)
Total	119,940	100.0	242,201	100.0

* Figures in brackets indicate percentage to total

Production : (Six yearly average ending 1989/90)	Arabica	78,500 Tonnes
	Robusta	77,500 Tonnes
	Total	156,000 Tonnes
Productivity per hectare : (1988)	Arabica	901 kgs.
	Robusta	1,078 kgs.
	Average	990 kgs.
Export earnings (1988/89) :	Quantity	133,361 Tonnes
	Value (Rs.)	357.86 Crores

Basically coffee (in the form of cherry) is dried under sun in the open yard. Matured coffee cherry contains moisture to a level of 60-65% (wet basis) depending upon level of maturity of the cherry. This has to be brought down to a standard level of 9.5% moisture content (w.b.). This is done partly at estate level and the remaining at coffee curing worker governed by coffee board. Then it is sent for dehusking (hulling), grading and roasting. Since the present method of drying coffee under sun consumes lot of space and during peak season there is a problem for storage of coffee, the curing agents feel that there is a need to develop an energy efficient dryer for coffee. In one of the coffee curing works, we found that one mechanical dryer has been installed which has a capacity to dry about 2500 kgs of raw coffee. The fuel used here is oil. They operate this dryer only during cloudy days or if the solar radiation is very low because this dryer is not economical as it consumes a lot of fuel oil.

In another mechanized dryer developed by Central Coffee Research Institute (CCRI) for parchment coffee, heated air is generated in a metallic furnace (which produces irradiated heat) by burning firewood, cherry husk or diesel (see Fig. 2.8). A temperature of 45°C is maintained for the initial 8 hours and thereafter 65°C till the end of drying. The temperature is monitored by regulating the burning rate of fuel. It has been given to understand that 70-80 kg of cherry husk is needed to operate the dryer at 65°C. The dryer is designed for batch processing having a capacity of 650 forlits by volume (1 forlit =

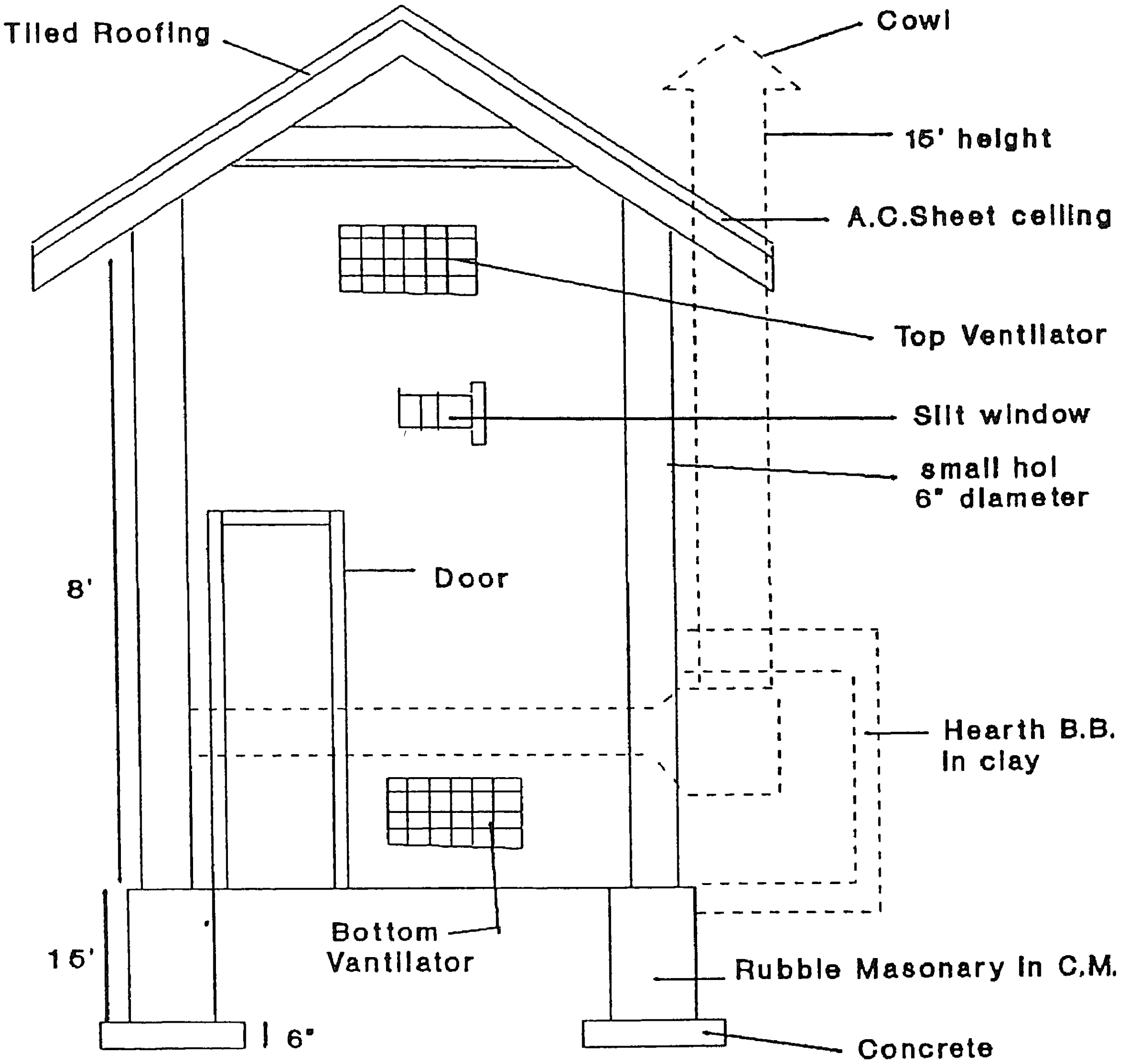

Fig. 2.8 Drying chamber for coffee curing at CCRI

40 liters). The process of drying fresh ripe cherry takes about 65-73 hours, while pre-dried cherry under sun for 4-5 days takes approximately 23 hours [8,9].

2.4 Copra

In India, coconut cultivation is spread over the entire coastal belt and some of the interior tracts where the conditions are favourable for its growth. Among the major coconut growing states in the country, there is considerable variation in the pattern of distribution of the crop. More than 90 per cent of the area and production of the coconut is concentrated in the four southern states of Kerala, Tamil Nadu, Karnataka and Andhra Pradesh with only limited spread in other states.

The distribution of area under and production of coconut is shown in Fig. 2.9 and share of four major coconut growing states is shown in Fig. 2.10 [10].

Tender coconut consumption is popular in the metros such as Bombay, Madras, etc. and is estimated at 5% of the total nuts production. Mature nuts constitute 95% of the annual harvest. Ten to fifteen million nuts are used for seednut purposes. The maximum use of mature nuts is in households for edible purposes and in religious and social functions which constitutes 56% of the nut production. The balance left is used for conversion into edible copra and desiccated coconut. On an average, 36% of production is diverted for conversion into milling copra leaving around 8% for production of desiccated coconut and in the form of copra [10].

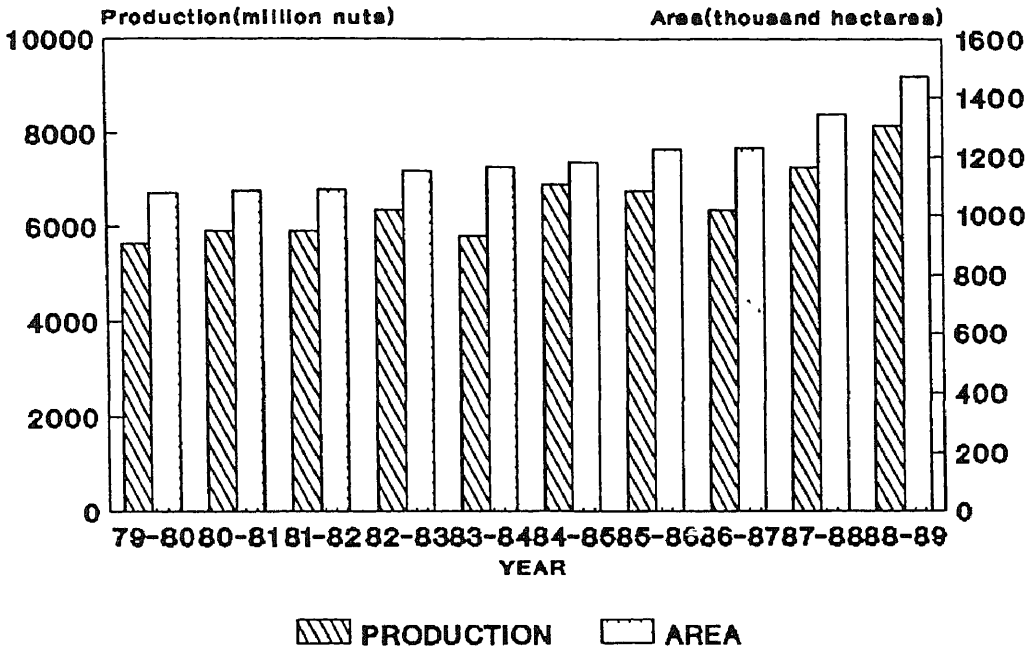

Fig. 2.9 Coconut: Area and Production in India

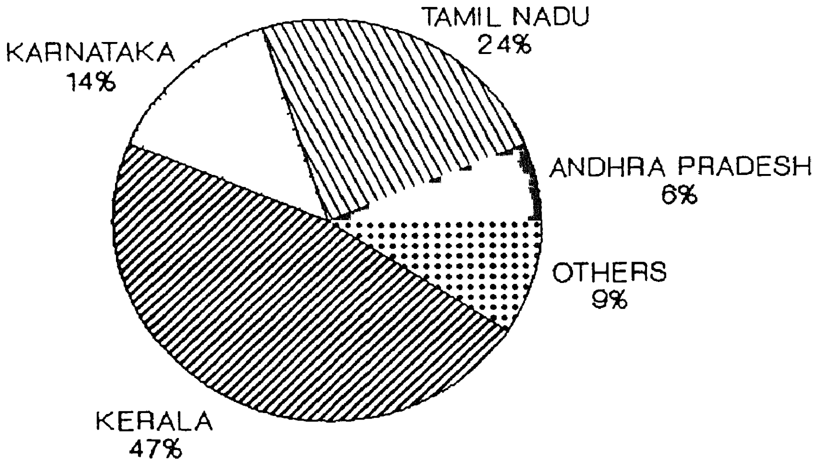

Fig. 2.10 Coconut production : share of major states
(for the year 1988-89)

The wet coconut kernel contains about 45-55% (w.b.) moisture which has to be dried to 6% (w.b.) moisture level to obtain the copra. The common practice of making copra is by drying the split coconuts under the open sun on cement or mud floor for 7 to 10 days. Copra obtained by this method is of poor quality because prolonged exposure under open conditions results in microbial infestation. Solar dryers are tried to reduce the drying time. CPCRI has developed three 'batch type' dryers (capacities of 400, 1000 and 3000 pieces of copras) having indirect heating and natural air convection arrangements [11,12]. The fuel used for drying is coconut husk/shell. The dryer is mainly comprised of:

(i) drying chamber
(ii) plenum chamber
(iii) burning cum heat exchanger unit
(iv) chimney with regulators.

The flue gas obtained by burning coconut husk/shell is passed through GI pipe laid inside the drying chamber (kiln) which heats the surrounding air by conduction and radiation (See Fig. 2.11). The hot air temperature is maintained at 70°C. Generally the drying is carried out over four days with overnight breaks till the moisture content of copra reaches to 6% (w.b.) for safe storage. Total drying time required is about 36 hrs and 30 kg of fuel is required to dry 400 nos. of copra pieces. CPCRI has also developed copra moisture meter to check the final moisture content of the copra [13].

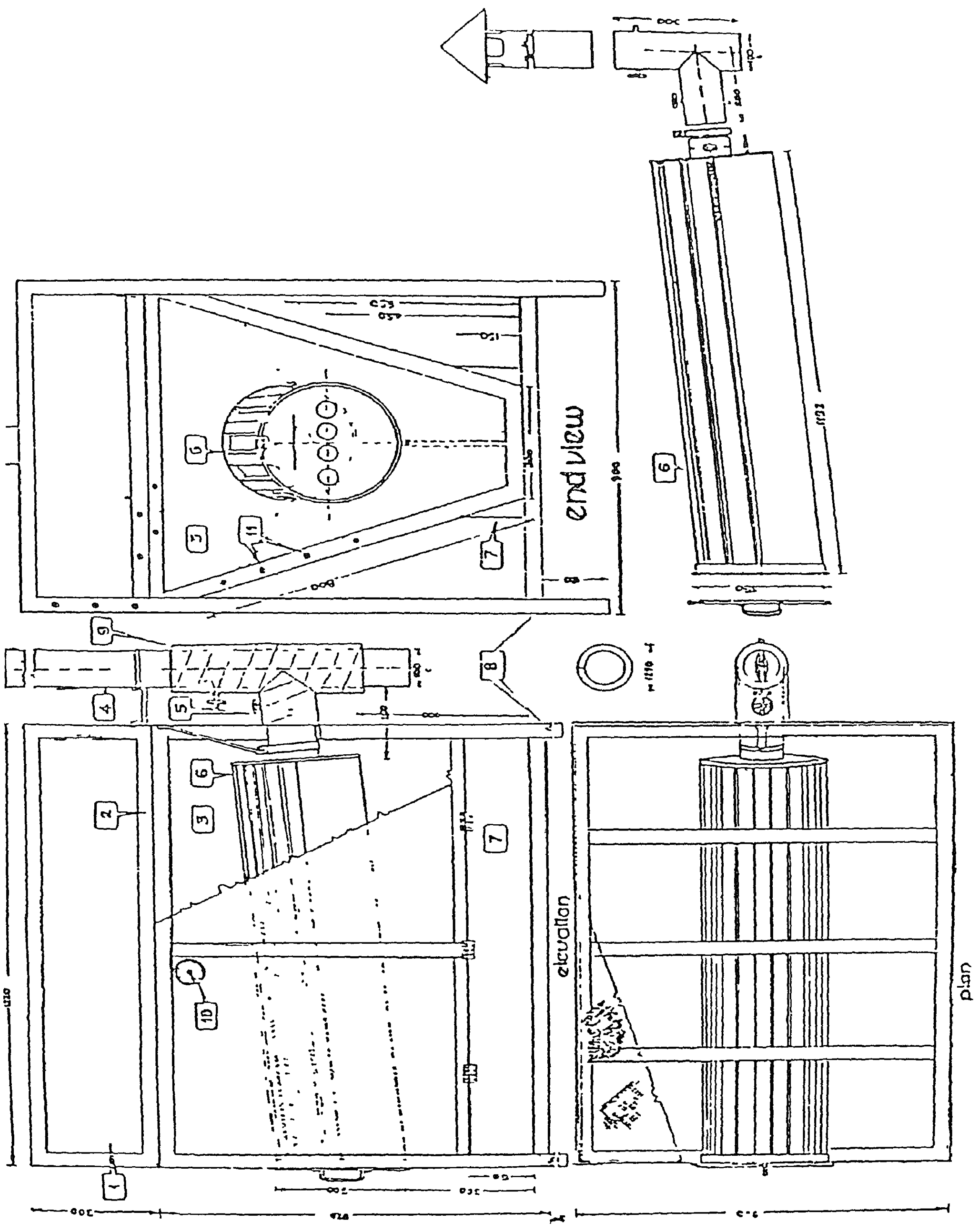

Fig. 2.11 Copra drying unit at CPCRI

2.5 Pepper

Pepper, the 'king of spices' is the dried fruit of a perennial climbing vine (Piper nigrum L). The vine starts yielding fruit by about the third year and continues to be productive for 15 to 20 years. Maximum yields are obtained in sixth to twelfth years. India is the largest producer and exporter of pepper with an estimated annual production of 31,580 tonnes from 1,14,180 ha. during 1977. Kerala alone contributes about 96% of country's production [14]. The year wise export of pepper from India is shown in Fig. 2.12 [15]. In India, spikes of pepper, 100-120 mm long containing 40-50 small round green berries get ready for harvest by about February. When the berries are fully mature and a few start turning yellow to red in each spike, the bunches are nipped off and collected in bags. The spikes are then dried in sun for 4-5 days to get black pepper. Figure 2.13 shows a photograph of pepper spread in the open yard for sun drying.

Processing of Black Pepper

The freshly harvested pepper has green colour and fresh flavour. The berries have moisture content above 70%. The berries, immediately after harvesting, are separated from spikes and spread out on mats for drying. In about 2 days, the moisture content decreases to 20-25%. Due to enzymatic oxidation of colourless compounds present in the skin, the colour of pepper turns black and masks the green colour that is left after drying. It is usually at this stage, pepper is purchased by an exporter. The subsequent operations involve further drying to safe moisture

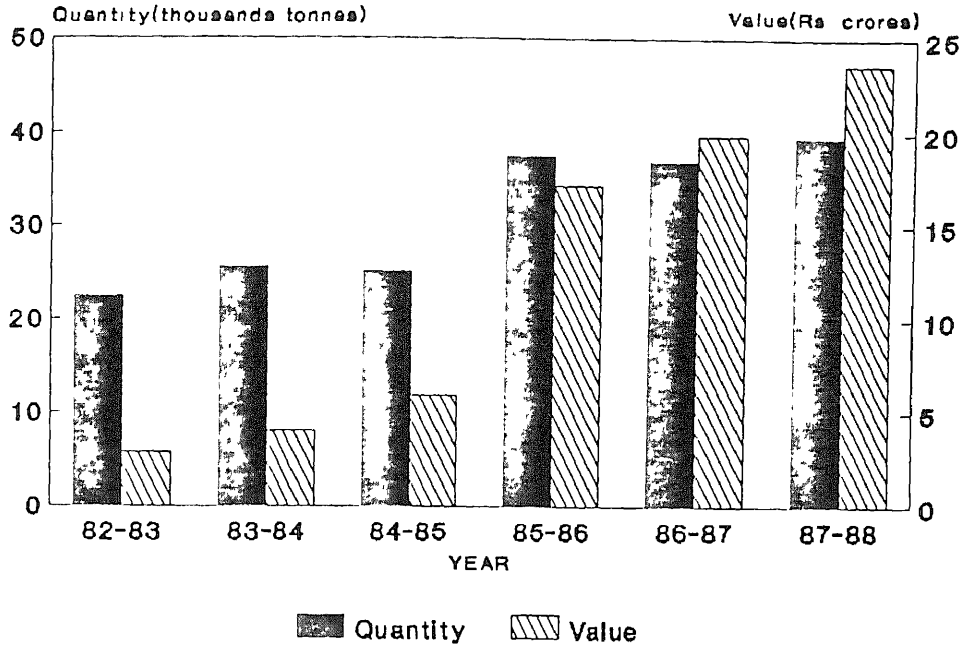

Fig. 2.12 Export of Pepper from India

Fig. 2.13 Open sundrying of pepper

levels below 11%. Humid climate causes problems during drying and storage. When the drying is inadequately done or when the pepper is stored at high moisture content, fungus appears on the product which affects its appearance. The safe storage moisture content of black pepper has been reported as 8.20% at 25-28^{o}C temperature and 28% rh. The mold growth appears on black pepper above 17.80% moisture or relative humidity above 73% [16].

Processing of White Pepper

White pepper is usually prepared from over-mature and ripe berries. At this stage, raw skin comes of easily and the resultant product can be dried. When skin is removed, a brown surfaced core covered by a thin silvery skin remains. The weight loss due to removal of outer skin is compensated by slightly higher weight gain due to maturation and around double the price obtained for this commercial product. The white powder obtained on grinding does not form detracts in light coloured soup and sauces. The safe storage moisture content for white pepper has been reported as 5.0% for whole and 6.6% for powder at 28^{o}C and 20% rh [16].

Processing of Green Pepper

In European countries, green or fresh flavour of pepper is liked in preparation of steak. Since it is not possible to obtain fresh pepper, canned and pickled under-mature pepper has become popular. There are two types of products, e.g. canned and bottled pepper. The former is heat sterilized and packed in cans and therefore, 2% salt solution suffices for proper protection. Because of prolonged heat treatment, the pepper

tends to become soft and in some cases berries burst, with consequent liberation of gelatinized starch, which makes the product inferior.

In bottled green pepper heat processing is avoided. Therefore, for good preservation, a higher salt strength up to 15-20% of surrounding liquid is essential. The berries in this case remain firm. Use of acid and sulfur dioxide help in preservation and prevention of blackening of the product.

2.6 Rubber

Statistics for 1980-1990 show the impressive performance of the rubber plantations. Production is almost doubled from 1,53,100 tonnes to 2,97,300 tonnes. The area is increased by 68% from 2.62 lakh hectares to 4.41 lakh hectares. Consumption is also increased by 98% from 1,73,000 tonnes to 3,42,000 tonnes (See Fig. 2.14). Productivity, in the form of yield per hectare, went up to 1,030 kg from 788 kg [17].

The crop collected from rubber plantation consists of latex (containing 30 to 40% dry rubber) and the various forms of field coagulum grades (like cuplump, shell scrap and tree lace). Normally the ratio of latex to field coagulum grades is 80:20 on a dry basis. Latex is processed into sheet (Ribbed Smoked Sheet - RSS, or Air Dried Sheets - ADS), Pale Latex Crepe (PLC) or Block Rubber and Latex concentrate. The field coagulum grades are processed to either estate brown crepe (EBC) or block rubber. Excepting latex concentrate, processing of all other forms of rubber involves drying operation. The types of drying equipment

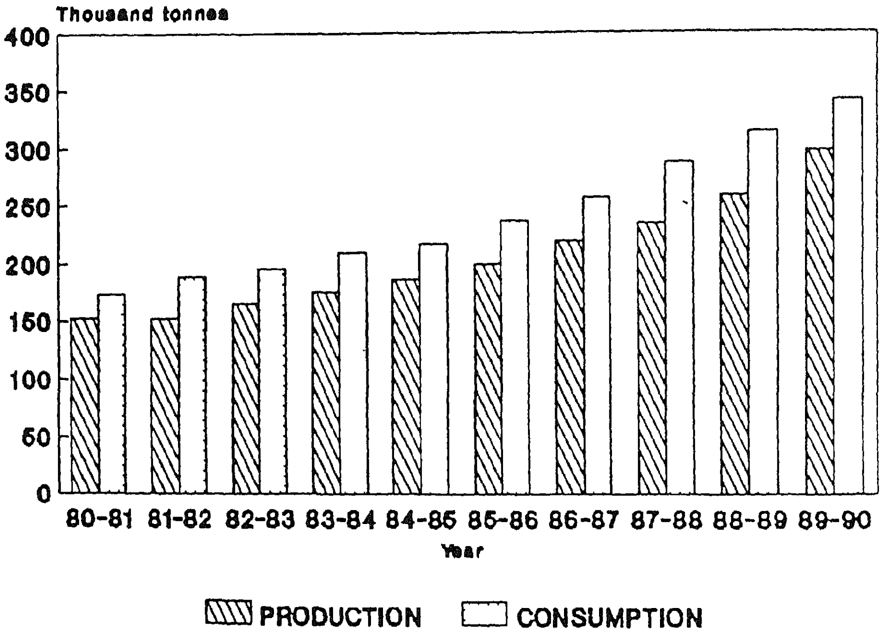

Fig. 2.14 Production and Consumption of Rubber in India

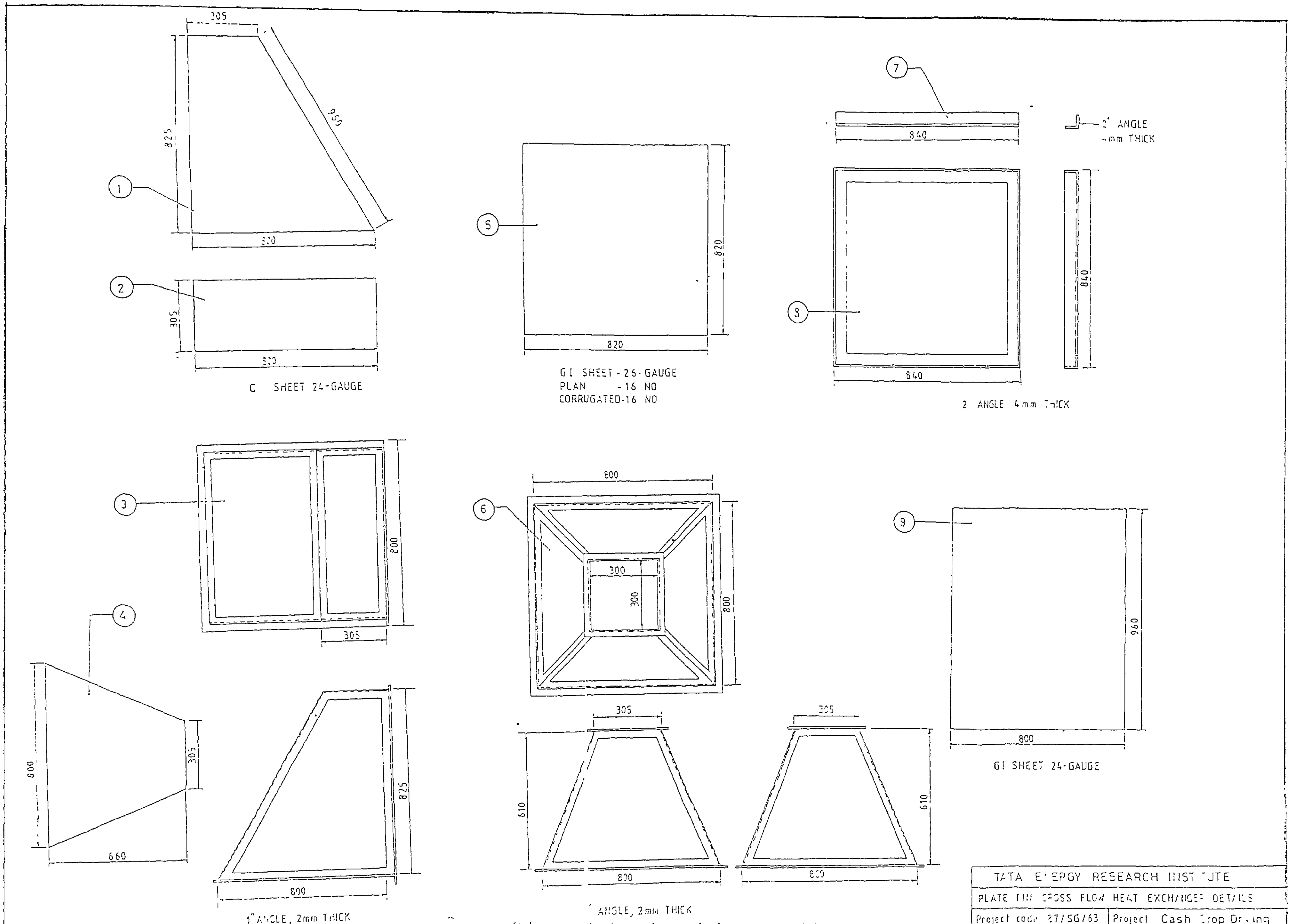

Fig 4 11(b) Detailed technical drawing of heat exchanger

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PLATE FIN CROSS FLOW HEAT EXCHANGER DETAILS					
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temperature of the chamber is increased from 45°C at the inlet point to 65°C at the exit point.

In conventional type, smoke house sheets are hung in four layers on barottes at a centre distance of about 3½". There is a furnace on one side outside the chamber and the gas is admitted to the bottom of the chamber through a tunnel. Temperature at the bottom i.e. near the fuel outlet is 45°C and at the top about 65°C. There is a chimney at the top with a baffle arrangement. The furnace is designed for controlled combustion of firewood. The temperature is regulated by adjusting the air inlet and the chimney opening. The wet sheets are loaded in the lowest layer and everyday the sheets are reversed and moved to the next layer. These type of smoke houses are available in capacities ranging from 20 to 200 kg/day. These are generally recommended for small holders, because of less capital cost.

Among small holders with production of 10 kg/day or less it is a common practice to dry the sheets initially for a few days under direct sun followed by a few days in the kitchen chimney.

Estate Brown Crepe (EBC)/Pale Latex Crepe (PLC)

The drying temperatures recommended for EBC and PLC are 32-34°C and 32°C respectively. Generally the practice is to dry at room temperature and the drying time of EBC and PLC varies from 7 to 20 days and 8 to 15 days respectively, depending upon the climatic conditions. The thickness ranges from 1 to 3 mm for EBC and that for PLC from 0.9 to 1 mm. The drying sheds are generally built for single or two tier loading of crepe. Roof extractors or vents are provided to give good air circulation. The crepe is hung 3 m high at about 4 to 5 inch centre distance [21].

Block Rubber

Processing of natural rubber into block forms is a relatively recent development which is popular among the leading natural rubber producing countries for more than a decade now. Currently about 35% of the world supplies of natural rubber is in this form.

In block rubber processing, the latex coagulum or field coagulum grades after a series of washing/cleaning/sheering operations is finally reduced in size by communition in hammer mill or extruder or shredder. The particles of rubber are then dried and baled into blocks.

The size reduction results in an enormous increase in the surface area which helps in reducing the drying time by having a higher drying temperature, compared to the other forms of rubber already described. The drying temperature is in the range 100-120°C and the drying time is 3½ to 5 hrs.

Energy is becoming costlier day by day and hence systems have to be designed for maximum utilization of energy. The energy utilization factor (kg of rubber dried per 1000 kcals) for various forms of dryers are given in Table 2.5. It could be seen that drying at higher temperatures help in reducing energy requirement. The higher energy requirement for drying at lower temperature is mainly due to higher heat losses, heating of large volumes of air and longer drying time [22].

Table 2.5: Typical energy utilization factors for different dryers

Type of rubber	Fuel	Drying temp ^{o}C	Drying time	Fuel requirement per tonne of dry rubber	kg. of rubber dried per 1000 kcals of energy
RSS	Firewood	57-63	4 days	800 kg	0.60
ADS	High Speed Diesel Oil	57-63	4 days	79 lit.	1.32
PLC	High Speed Diesel Oil	32-34	6 days	81 lit.	1.29
PLC	Electricity	32-34	6 days	702 kWh	1.66
Block Rubber	High Speed Diesel Oil	100-120	3½-5 hrs	50 lit.	2.09
Block Rubber	Electricity	100-120	3½-5 hrs	410 kWh	2.84

2.7 Tea

In tea processing, energy is used at various unit operations. Two processing methods, "CTC" (crush or cut tear-curl) and "Orthodox" (or classical), have generally been adopted by tea manufacturers. Around 56% of manufacturers use CTC and the remainder use orthodox method. The important processes and their conditions involved in tea manufacture are shown in Fig. 2.15 [23].

The production of tea from green leaves is essentially a gradual oxidation process. Green leaves after harvest undergo the following stages:

(i) withering

(ii) rolling & cutting

(iii) fermentation

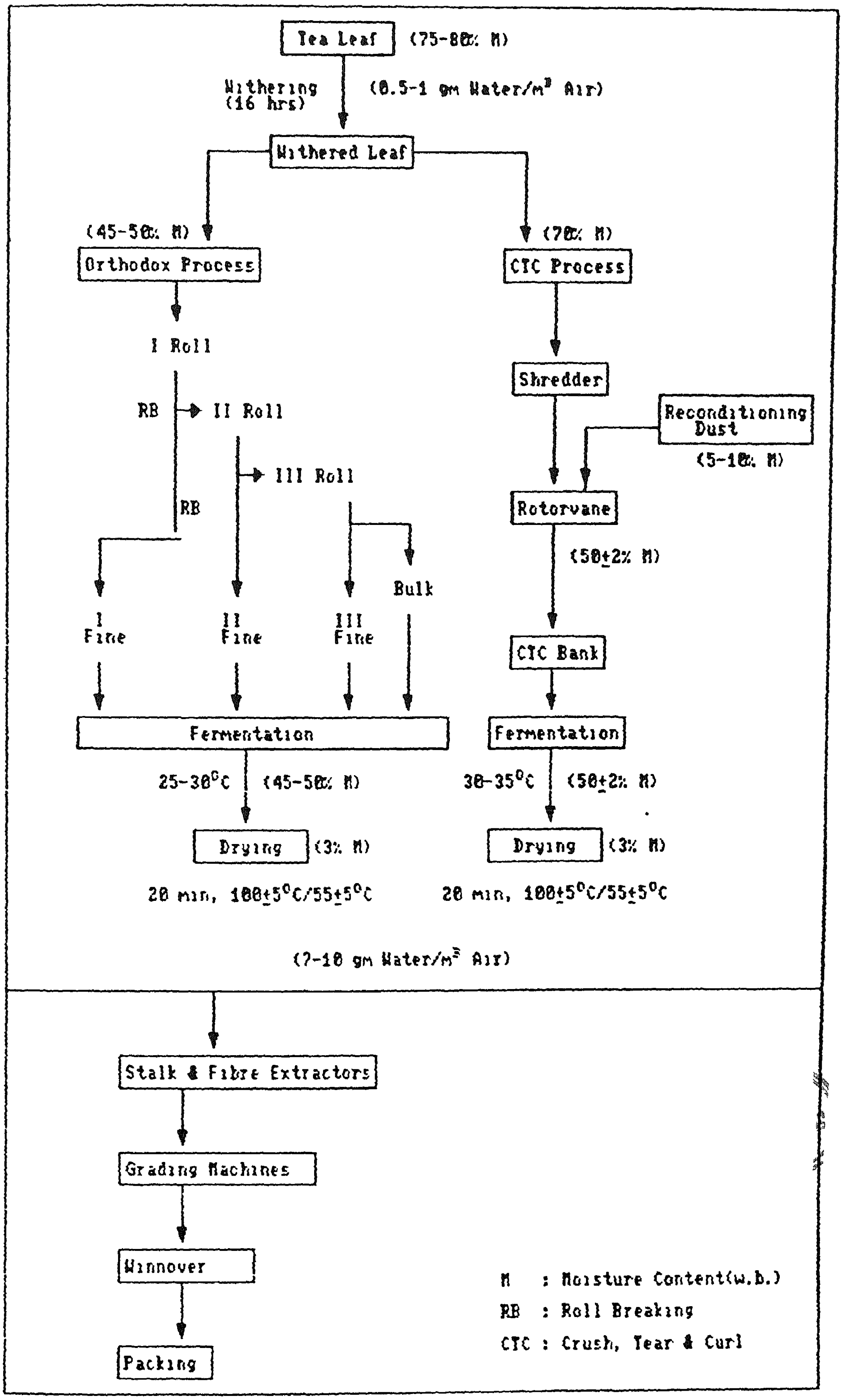


Fig. 2.15 Tea Manufaturing Process
]

(iv) drying
(v) grading.

The land-harvested, tender green leaves have an initial moisture content of 80% (w.b.). During withering, in orthodox process, the moisture content of green leaves is reduced to 50-55% (w.b.) and in CTC process the moisture content is reduced to 70-72% (w.b.).

The rolling stage involves tearing, cutting and crushing which causes the leaf to begin to change colour from green to copper-red. The types and number of rollers employed in CTC and orthodox methods are different. With CTC process, black tea dust (from final stage) is added to adjust moisture content to approximately 50% (w.b.). Figure 2.16 shows photograph of machines used for CTC tea.

The oxidation process reaches its maximum intensity during the fermentation stage. It involves placing the rolled leaves on static beds or in slowly rotating drums at room temperature (10-22°C) and with increased humidity (humidifier provides the desirable condition). About 1 to 2 hrs are required for CTC and 3 to 4 hrs for orthodox.

In the final stage (drying), the fermented leaves are fed into a tray dryer by conveyer through a stream of hot air at a temperature of 88-93°C for 24-26 minutes. During drying the copper-red colour changes to black with a final moisture content of 2 to 3% (w.b.). Then the dried product is graded and sent for packaging.

Fig. 2.16 CTC (curl-tear-cut) machine of tea factory

In Table 2.6, the electrical and thermal energy consumption is reported on the basis of the time necessary for each stage and power of the machines (blowers and electrical motors) in a tea processing factory [24].

Table 2.6: Average thermal and electric consumption in tea factories

Process Stage	**Energy Consumption: CTC**		**Energy Consumption: Orthodox**	
	Thermal	**Electric**	**Thermal**	**Electric**
	(kWh/kg of tea)		**(kWh/kg of tea)**	
Withering	0.70	0.11	1.08	0.14
Drying	3.80	0.04	3.30	0.04
Others (1)	Nil	0.45	Nil	0.40
Total	4.50 (2)	0.60 (3)	4.38	0.58

(1) Rolling, fermentation, grading and packing
(2) Range evaluated : 3.78 - 5.22
(3) Range evaluated : 0.55 - 0.65

The conventional tea dryer consists of four main parts:

(i) Furnace for burning fuel (fire wood, coal, leco).

(ii) Cast iron tube banks through which or around which the atmospheric air passes and gets heated up (See Fig. 2.17).

(iii) A sucking fan which sucks hot air through the tube banks and pushes it into the drying chamber.

(iv) An induced draft fan which sucks out the exhaust gases, ash, etc. and lets these out through the chimney.

Generally 60% of the heat supplied by fuel is lost in furnace and heat exchanger and only 40% of the heat is

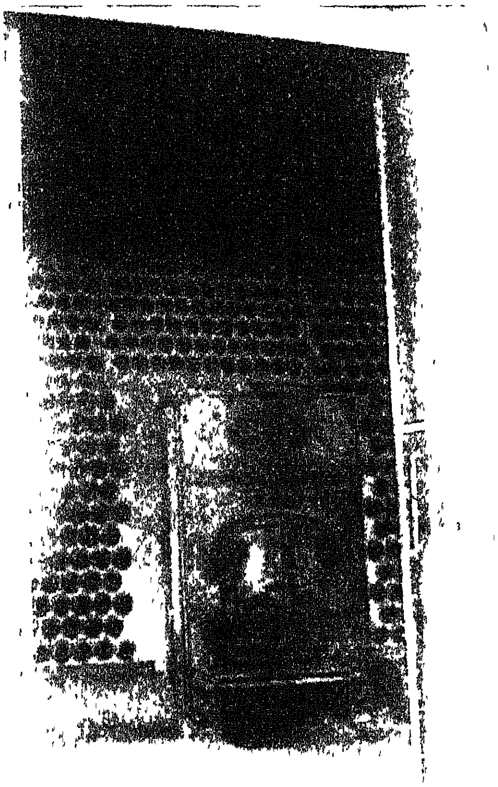


Fig. 2.17 Furnace and tube bank for air heating in tea factory

transferred to hot air entering the dryer. Nearly half of it is lost in the dryer exhaust and one third to fixtures, exit tea and insulation losses [25]. There is lot of wastage of heat and therefore considerable scope for improvement.

2.8 Tobacco

India produces about 450 million kg of tobacco annually from an area of about four lakh hectares (ha) which accounts for about nine per cent of the world area and 7.5 per cent of world production. It has 0.3 per cent of the total cropped area in the country (See Fig. 2.18). Endowed with various agro-climatic zones, India grows all types of tobacco (except oriental), which are broadly classified as flue-cured virginia (FCV) (cigarette tobacco) and non-virginia types. FCV tobacco accounts for 30 per cent of the area and 22 per cent of production while the non-virginia type comprising bidi, natu, chewing, hookah, cigar and cheroot, burley and snuff tobaccos, accounts for the remaining 70 per cent of the area with a production of about 350 million kg. Tobacco provides about Rs. 1,500 crores of Central excise revenue and earns Rs. 150 to 170 crores of foreign exchange through exports. Table 2.7 gives details about area and production of various tobacco varieties in India [26].

Flue curing is an important process in the production of flue cured virginia (FCV) tobacco which is carried out in closed chambers called "barns" (ordinary/conventional type). The barn is loaded with optimum density of tobacco leaves for proper curing. The barn is loaded uniformly to provide proper air and heat movement through the tobacco. The barn is a tight,

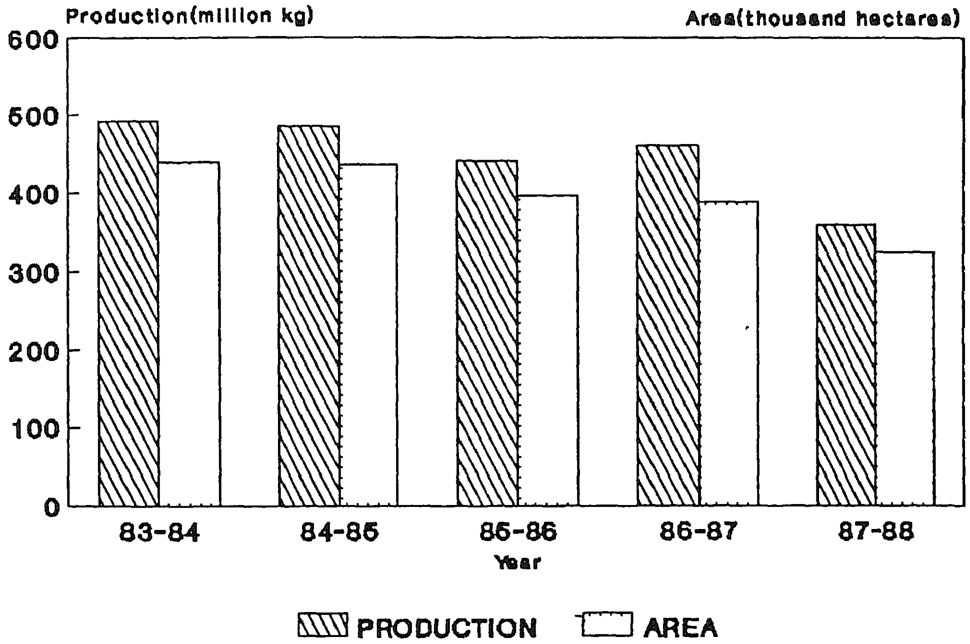


Fig. 2.18 Production and Area of different Tobacco varieties

Table 2.7 Area and production of tobacco varieties

Type	1983-84		1984-85		1985-86		1986-87		1987-88	
	Area+	Production*	Area	Production	Area	Production	Area	Production	Area	Production
Virginia	152.3	130.0	133.1	110.0	115.9	79.6	117.9	109.5	88.0	64.3
Natu	40.0	53.0	48.0	53.0	42.0	58.0	37.0	45.0	35.0	40.0
Bidi	128.0	175.5	126.0	175.0	127.0	173.0	130.0	185.0	100.0	135.0
Cigar & Cheroot	14.0	14.9	16.6	19.4	12.4	17.7	10.0	11.0	10.0	10.0
Hookah	29.7	31.2	30.0	33.0	28.0	30.0	24.0	28.0	24.0	28.0
Chewing	69.2	78.7	75.5	89.0	67.0	75.0	65.0	78.0	60.0	75.0
Snuff	6.5	9.2	7.4	6.5	4.7	7.9	5.3	5.3	6.9	6.6
Total	439.7	492.5	436.6	485.9	397.0	441.2	389.2	461.8	323.9	358.9

+ Area : 1,000 hectares
* Production : million kg

insulated structure and at the same time having enough ventilation. The interior portion of the barn consists of horizontal poles called "tiers". The normal size of the barn is 4.9 m x 4.9 m x 4.9 m. The tier poles are placed 4′ apart horizontally and 2′ vertically. The first tier is placed 5′-6" (1.7 m) above the ground level (See Fig. 2.19) [27].

The inside wall of the barn is plastered with red earth mixed with paddy husk for more efficiency. Bottom and top ventilators are provided for the barn. The position of the bottom ventilators or holes, should always be just below the flue pipes for effective air circulation (See Fig. 2.20).

The furnace is placed at one side of the barn on the ground level. The furnace has an arch with fire bricks. The bottom of the furnace is provided with fire bars and below the fire bars, there is an air inlet chamber. The first length of the flue pipe is a cast iron pipe. From the cast iron pipe, flue gases run

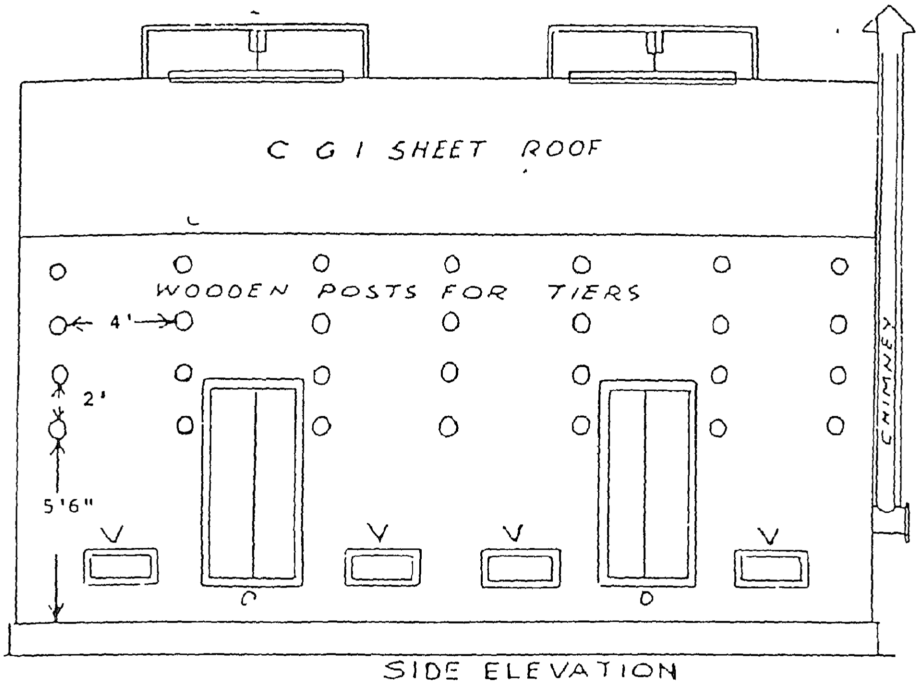


Fig. 2.19 Conventional barn for tobacco flue curing

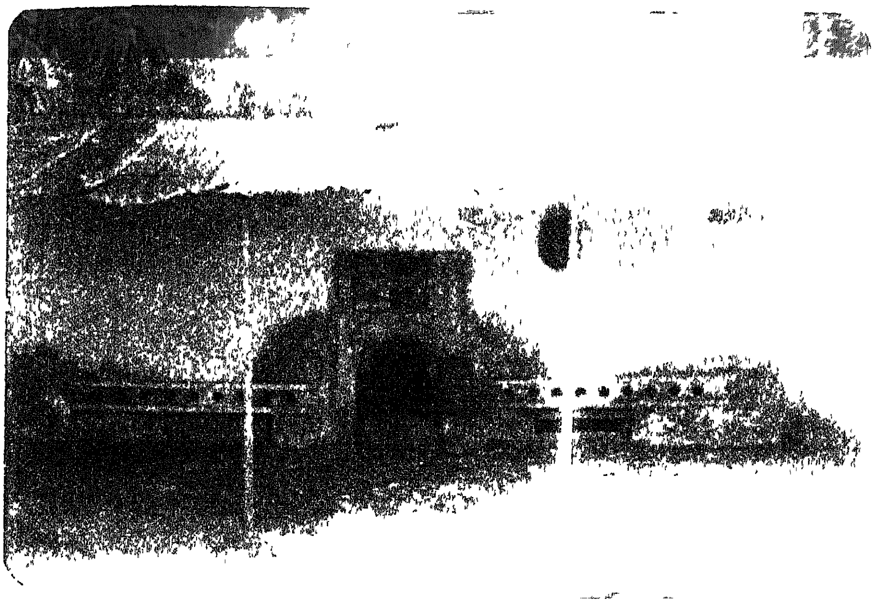


Fig. 2.20 Tobacco barn showing furnace and ventilator holes

towards the door and there they will take a 'T' turn. After extending to the side of the barn and again they take right angle bend near the furnace and both the flue pipes join over the furnace and pass out through the wall.

The different stages during flue curing of tobacco are:

(i) Yellowing

(ii) Colour fixing

(iii) Leaf drying (laminar drying)

(iv) Steam drying (Midrib drying).

The tobacco leaves are dried by natural convection flow of hot air over the tiers. The total time required for flue curing of tobacco is around 120 hours. Generally coal is used as fuel for flue curing of tobacco and 1.25 kg of coal is required to cure 1 kg of green tobacco leaves.

Table 2.8 gives the temperature and time required at each stage during the flue curing of tobacco [28].

Table 2.8: Temperature and time requirement at different stages of tobacco flue curing

S.No.	**Stage**	**Temperature (^{o}C)**	**Time (hrs)**
1.	Yellowing	30-40	30-40
2.	Colour fixing	40-50	3-9
3.	Leaf drying (laminar drying)	50-65	20-30
4.	Stem drying (Mid rib drying)	65-70	26-43

An improved design of low profile barn (LPB) of 7.3 m length, 4.9 m width and 2.3 m height was developed by CTRI, is shown in Fig. 2.21. Curing in the low profile barn is more advantageous and economical than the conventional barn in respect of curing time and coal consumption [29]. LPB attains the required temperature uniformly all over the barn.

Heat required in kcal for barn with 1452 cubic feet capacity of conventional construction capable of curing 620 kg of green tobacco leaves at Rajahmundry is given in Table 2.9 [30].

Table 2.9 Heat required in different stages of tobacco drying

	Process (curing)	Barn Losses	Required by Fixtures	Total
Yellowing	675	18,880	774	80,670
Colour fixing	3,758	24,859	3,870	32,487
Laminar drying	227,913	117,852	4,839	350,333
Mid-rib drying	75,908	211,425	3,870	291,203
Total	308,254	372,746	13,352	694,352

2.9 Summary of Survey

Survey of drying systems for various cash crops described in sections 2.1 to 2.8 indicates that drying requirements such as drying time, drying temperature, initial and final moisture content levels etc. for majority of cash crops are similar for most traditional drying methods which can be summarised as below:

Drying temperature	45-70°C
Drying time	20-120 hrs

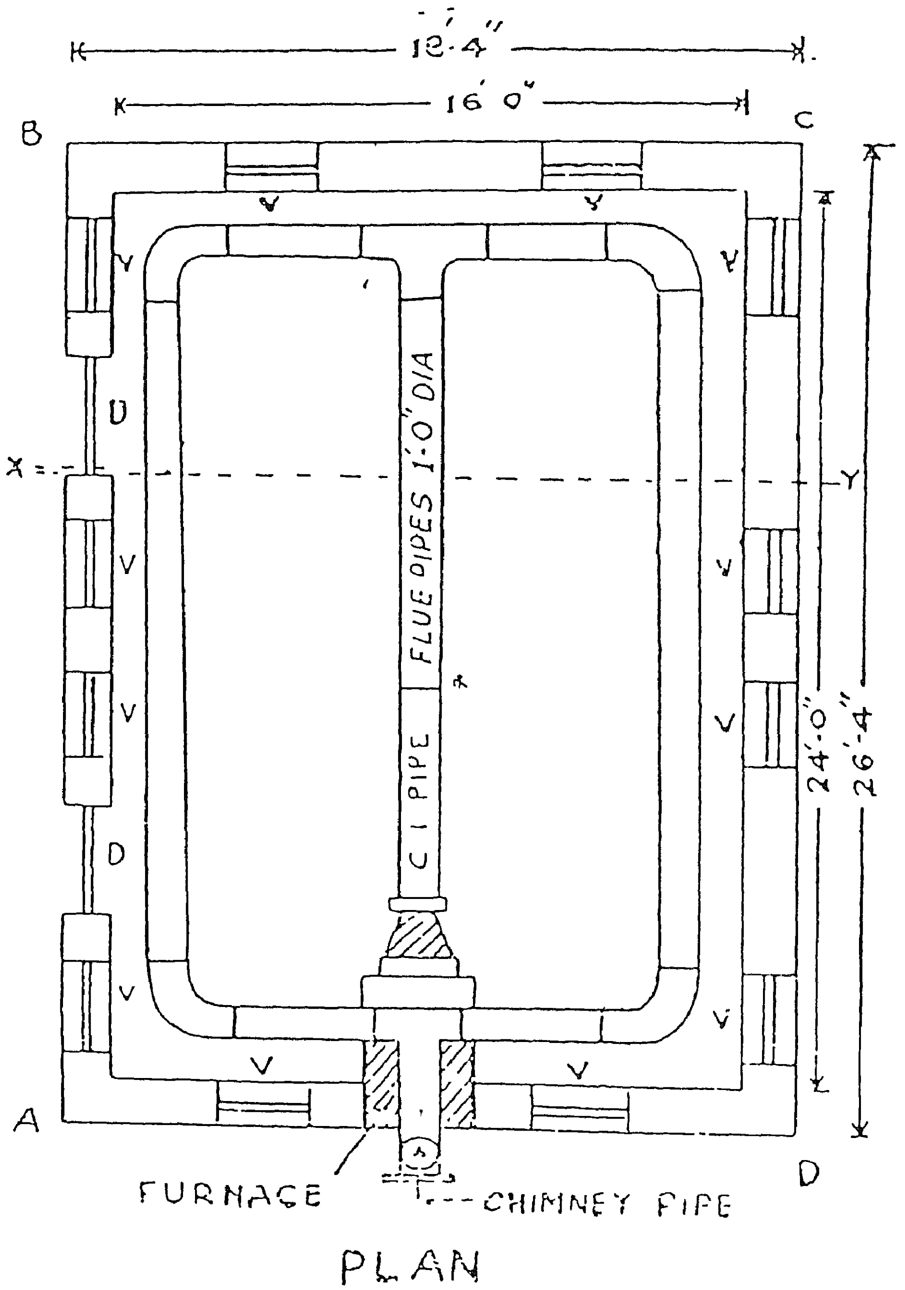


Fig. 2.21 Low profile barn for tobacco flue curing

Initial moisture content	50-80% (w.b.)
Final moisture content	3-10% (w.b.)

Among the major cash crops cardamom curing is a delicate process. Cardamom has to be dried under controlled atmosphere in order to maintain its fresh green colour as it fetches more price in the market. Faster drying of the capsules results in bubbling and splitting of the outer shell whereas higher humidity levels and over heating results in pale green or yellow colour of the capsule.

So, cardamom is selected as a representative cash crop for detailed study under this project. The drying system developed for this can be utilised for drying other crops after tuning the system for required air temperature and flow rate for that particular crop.

3. THERMAL ANALYSIS OF THE CONVENTIONAL CURING CHAMBERS: A CASE STUDY FOR CARDAMOM

As mentioned in the previous chapter the conventional cardamom curing chamber operates on the method of space heating with a heat exchanger. Hot flue gases, obtained by combustion of firewood, are passed through a metal pipe laid inside the curing chamber and air surrounding the flue pipe gets heated up and rises to the top of the curing chamber by natural convention, (See Fig. 2.3). From the survey of the existing cardamom curing chambers it is clear that they are operating at very low thermal efficiencies, of the order of 3 to 8%, resulting in a huge wastage of fire wood. Before designing an improved drying system it is necessary to analyse the existing curing chamber to understand the reasons for their low efficiency. So in this chapter an attempt has been made to study the heat transfer characteristics of the conventional curing chamber. A mathematical model developed here explains the behaviour of the curing chambers which throw light on the drawbacks of the present system causing low thermal efficiency and also gives hints by which it can be improved.

3.1 Mathematical Model

A schematic diagram of the heat exchanger used in the conventional cardamom curing chamber, which is just a single flue gas pipe laid in the chamber is shown in Fig. 3.1. Hot flue gases enter the pipe at a temperature Tg_{in} and leave the pipe at a temperature Tg_{out}. The air surrounding the flue pipe is heated from initial temperature Ta_{in} to a temperature Ta_{out} by natural convection. This configuration is very similar to a cross flow

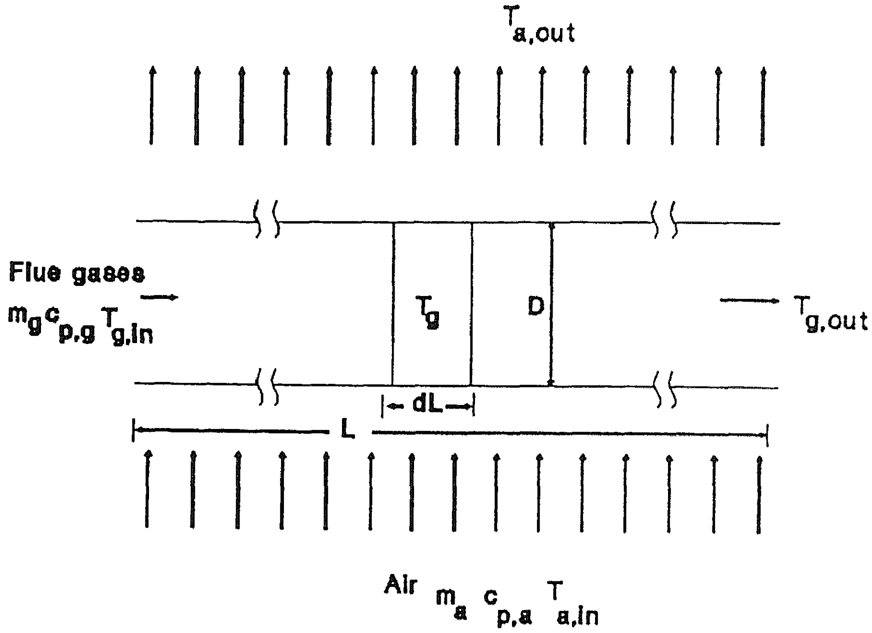


Fig. 3.1 Schematic diagram of heat exchamger used in conventional cardamom curing chamber

heat exchanger [31]. A heat balance of the element dL in the axial direction yields the equation

$$m_g \; c_{pg} \; dT_g = U \pi D \; dL \; (T_g - Ta_{avg}) \tag{1}$$

where $Ta_{avg} = (Ta_{in} + Ta_{out})/2$

Integration of equation (1) over the length of the pipe 'L' gives:

$$\ln \left[\frac{Tg_{out} - Ta_{avg}}{Tg_{in} - Ta_{avg}} \right] = \frac{-U \pi D L}{m_g \; c_{pg}} = \frac{-U A}{C_g} \tag{2}$$

A total heat balance of the system gives,

$$m_g \; c_{pg} \; (Tg_{in} - Tg_{out}) = m_a \; c_{pa} \; (Ta_{out} - Ta_{in}) \tag{3}$$

As per the standard heat exchanger theory the following terms are defined.

(i) Number of transfer units

$$N = \frac{U A}{C_a} \tag{4}$$

(ii) Capacity rate ratio

$$R = \frac{m_a \; c_{pa}}{m_g \; c_{pg}} = \frac{C_a}{C_g} \tag{5}$$

(iii) Heat exchanger effectiveness

$$E = \frac{m_a \; c_{pa} \; (Ta_{out} - Ta_{in})}{m_g \; c_{pg} \; (Tg_{in} - Ta_{in})} = \frac{Tg_{in} - Tg_{out}}{Tg_{in} - Ta_{in}} \tag{6}$$

The above equation can be written with some algebraic manipulations, in the following form:

$$E = \left[\frac{1}{1 - \exp(-R.N)} + \frac{1}{2R} \right]^{-1}$$

This is similar to the equation for a cross flow heat exchanger given by Holman [32]. A plot of E vs. N for different values of R is shown in Fig. 3.2. In heat exchanger theory E has the significance of the thermodynamic efficiency of the heat exchanger. It is defined as the ratio of actual amount of heat transferred to the maximum possible amount of heat that can be transferred. From Fig. 3.2 it can be seen that higher effectiveness, up to 0.9, can be obtained for higher capacity rate ratios. To get an idea of the efficiency at which the conventional curing chamber heat exchanger operates, it is necessary to evaluate various parameters such as mass flow rates, heat transfer coefficients etc. This is done in the following sections.

3.2 Numerical Calculations

For a conventional curing chamber the following data are available.

Volume of curing chamber	138.25 m^3
Amount of green cardamom per batch	200 kg
Fuel consumption per batch	750 kg
Drying time	36 hr
Flue gas temperature near oven	250^oC
Diameter of flue pipe	0.204 m
Length of the pipe inside the chamber	11.968 m
Area of the oven in the chamber	0.86 m^2

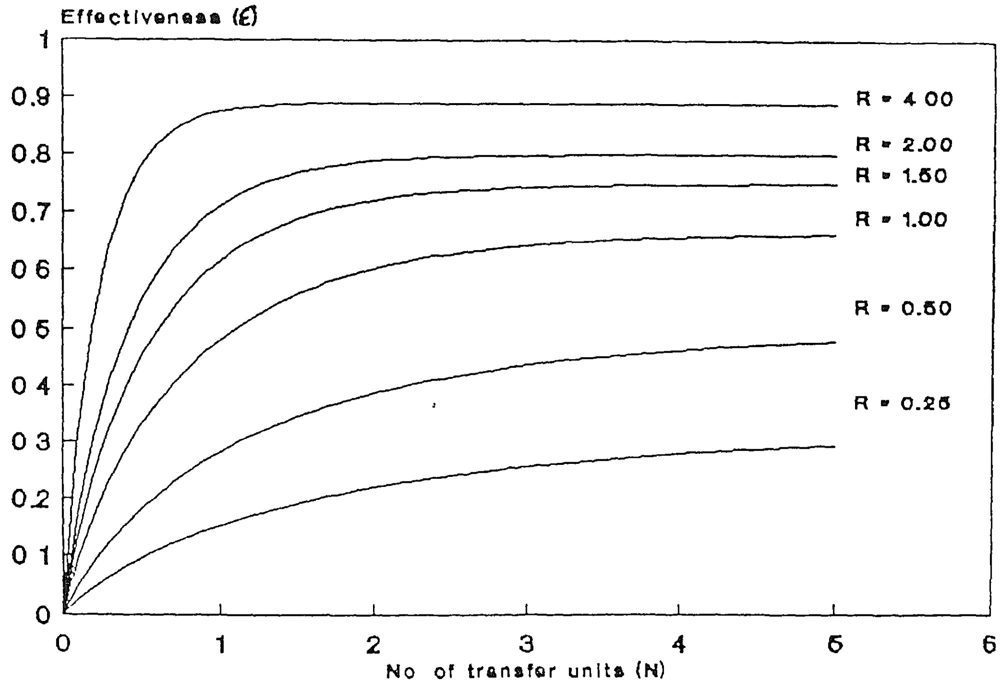


Fig. 3.2 ε- NTU curves for the heat exchanger used in conventional cardamom curing chambers

The flue gas flow rate depends mainly on the burning rate of the fuel and on the furnace design. The stoichiometric air requirement for complete combustion of 1 kg of wood is 5 m^3 at STP [33]. In actual practice the amount of air entering the furnace is always greater than stoichiometric air. Hence the excess air factor is defined as:

$$EAF = \frac{\text{actual amount of air consumed in combustion}}{\text{theoretical amount needed for complete combustion}} \quad (8)$$

For a given burning rate the volume of flue gases produced at STP is approximately equal to the volume of air entering the furnace at STP [33].

$$m_g = 5 \; EAF \; m_f \rho_o \quad (9)$$

The various properties of flue gases are summarised in Table 3.1 [33].

Table 3.1: Properties of flue gases at STP

Quantity	Value
ρ_o (kg/m^3)	1.27
c_g (kJ/kg^oC)	1.05
μ_g (kg/m^oC)	16.0E-6
k_g (W/m^oC)	0.028

A heat balance of the furnace gives

$$m_g \, c_{pg} \, (Tg_{in} - T_{amb}) = \eta_f \, m_f \quad (10)$$

Substituting for m_g from equation (9) one gets

$$EAF = \frac{\eta_f \lambda}{5 \rho_o (Tg_{in} - T_{amb}) c_{pg}} \qquad (11)$$

The efficiency of the furnace is unknown but can be reasonably assumed to be about 0.6 [3].

The velocity of flue gases in the flue pipe V_g can be calculated from:

$$\frac{\pi}{4} D^2 V_g \rho_o \left[\frac{273}{273 + Tg_{in}}\right] = m_g$$

$$V_g = \frac{4}{\pi} \left[\frac{273 + Tg_{in}}{273}\right] \frac{m_g}{\rho_o D^2} \qquad (12)$$

The Reynolds number Re is

$$Re = \frac{\rho_g V_g D}{\mu_g} = \frac{\rho_o V_g D}{\mu_g} \left[\frac{273}{273 + Tg_{in}}\right] \qquad (13)$$

The heat transfer coefficient on the flue gas side h_g can be calculated from the expression [34].

$$Nu = 0.023 \; Re^{0.8} \; Pr^{0.4} \qquad (14)$$

where

Nu = Nusselt number $= \frac{h_g D}{k_g}$

Pr = Prandtl number $= \frac{\mu_g c_{pg}}{k_g}$

The convective heat transfer coefficient for air (laminar flow) heated outside horizontal circular pipe is given by [35].

$$h_a = 1.32\ (\Delta T/D)^{1/4} \tag{15}$$

Where $\Delta T = Tg - Ta$

The overall heat transfer coefficient is given by:

$$U = [(1/h_g) + (1/h_a)]^{-1} \tag{16}$$

Thus using above equations and data for conventional curing chamber the values obtained for all parameters are given below:

Flue gas side

$m_f = 20.83$ kg/hr

EAF = 8.05

$m_g = 1064.6$ kg/hr

$C_g = 310.5$ W/°C

$V_g = 11.43$ m/sec

$Re = 1.15 \times 10^5$

$Pr = 0.6$

$Nu = 150$

$h_g = 20.6$ W/m^2°C

Air side

$C_a = 99.0$ W/°C

$h_a = 7.35$ W/m^2°C

Heat exchanger performance

$U = 5.4$ W/m^2°C

$A = 8.53$ m^2

$N = 0.465$

$R = 0.32$

$E = 11.3\%$ (from equation (7) or Fig. 3.2

Thus it can be seen that the heat exchanger of the conventional curing chamber is operating with an efficiency of 11.3%. For the furnace efficiency of 60%, the overall achievable efficiency of the curing chamber comes out to be 6.8% (with no heat losses from the walls). The actual efficiency calculated from the amount of water reported from cardamom and the amount of wood consumed is 2.57%.

3.3 Guidelines for improvement Based on Thermal Analysis of Conventional Curing Chamber

From the above thermal analysis of the conventional curing chambers it can be concluded that the bottleneck in realising high thermal efficiencies is the heat exchanger design. The capacity rate ratio R is very low because of little amount of air circulation due to natural convection. This results in a low heat transfer coefficient on air side, and thus decreases the overall heat transfer coefficient resulting in poor heat exchanger effectiveness.

Thermal efficiency can be improved by following ways:

(i) increase in capacity rate ratio by using forced flow methods for air.

(ii) improved furnace design with low excess air factor

(iii) increasing the heat transfer area of the heat exchanger by opting for compact heat exchanger such as plat fin type heat exchanger.

The design of such an improved system is given in the next chapter.

4. FIRST PROTOTYPE DRYING UNIT DESIGN AND FABRICATION

After doing survey of several cash crop drying systems in South India, it was decided to develop a drying system for cardamom as a sample which can be utilized for other crops also with some necessary modification to tune the system to the specific requirements of that particular crop e.g. air velocity, temperature etc. Cardamom drying is a delicate process since any deviation from design conditions affects its colour which sharply brings down its market price. Higher temperature and velocity causes discolouration of capsule and faster moisture removal rate may result into splitting of the shell.

From the thermal analysis of the existing curing chambers done in the previous chapter it is observed that the main bottleneck in realizing higher thermal efficiency is the heat exchanger design. Design of the improved dryer unit endeavors to overcome the drawbacks of the conventional system by utilizing forced flow methods on the air side and using compact and highly efficient heat exchanger design. The heart of the proposed system is a plate-fin type compact cross flow heat exchanger with a significant improvement in heat exchanger effectiveness.

The schematic diagram of the drying unit is given in Fig. 4.1 showing various components. It consists of a furnace, a heat exchanger, an air blower, and a dryer cabinet. The furnace is made up of mild steel. Provision is made to control the primary as well as secondary air supply. Proper insulation is provided on furnace walls and around the duct which carries flue gases to heat exchanger in order to reduce heat losses.

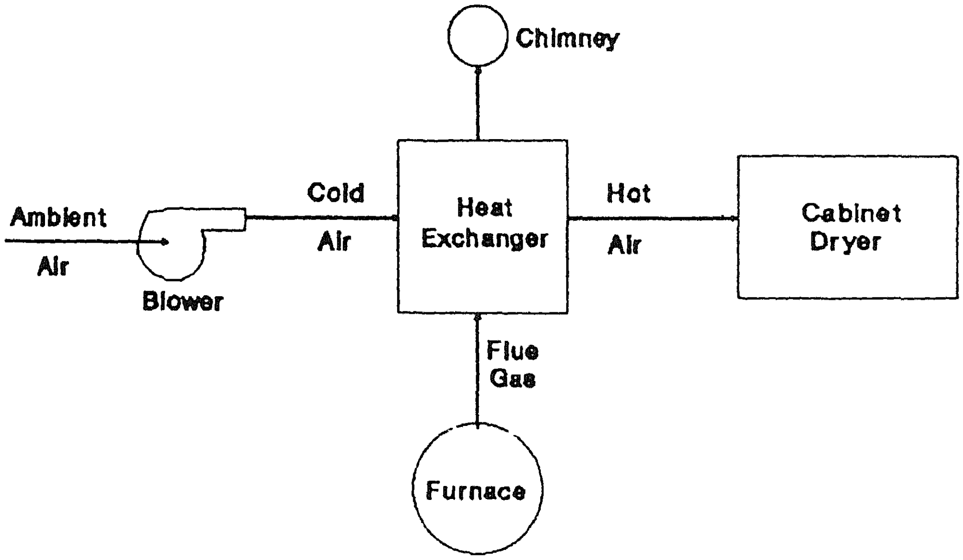


Fig. 4.1 Schematic diagram of proposed drying system

The heat exchanger used is a compact plate-fin type cross flow (both fluids unmixed) heat exchanger. Heat exchanger is a cube of length L. At present GI corrugated sheets are used for plate fins, but other material can be used if corrosion problems appear to be severe. The schematic of heat exchanger is shown in Fig. 4.2 showing air and gas flow directions. An air blower is used to increase the heat transfer coefficient in the heat exchanger and to accelerate the drying rate in the cabinet tray dryer.

4.1 Methodology to Predict System Performance

The method to predict the performance of the drying unit is discussed below.

Furnace calculations:

1. From the elemental analysis of the fuel determine the stoichiometric air requirement. Select a particular burning rate.
2. For a given excess air factor (EAF) and for the selected burning rate, the flow rate and temperature of the flue gas can be obtained by iterative methods, using the proper material and energy balance equations.
3. After accounting for losses from furnace and ducting, calculate the temperature ($T_{g\ in}$) of flue gases entering into the inlet of heat exchanger.

Heat Exchanger Calculations:

A particular configuration and dimensions of the heat exchanger are fixed initially. For drying a particular cash crop

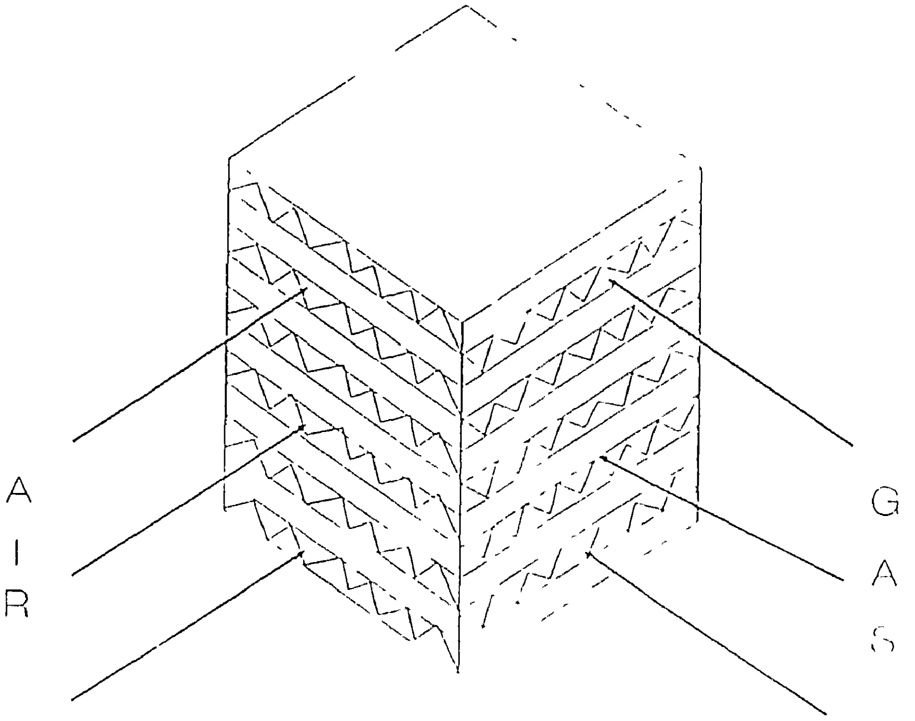


Fig. 4 2 Schematic diagram of heat exchanger it is necessary to control the hot air temperature at the inlet of dryer. Thus the temperature of hot air leaving the heat exchanger ($T_{a\ out}$) is fixed for a particular crop. Knowing flue gas flow rate (m_g) gas inlet temperature ($T_{g\ in}$), air inlet and outlet temperature ($T_{a\ in}$ and $T_{a\ out}$) and thermal properties of air, the performance of heat exchanger can be evaluated using the following basic equations:

$$m_a\ c_{pa}\ (T_{a\ out} - T_{a\ in}) = m_g\ c_{pg}\ (T_{g\ in} - T_{g\ out}) \tag{1}$$

where c_{pa} and c_{pg} is specific heat of air and gas respectively.

$$\frac{1}{U} = \frac{1}{ha} + \frac{1}{hg} \tag{2}$$

$$C_a = m_a\ c_{pa} \tag{3}$$

$$C_g = m_g\ c_{pg} \tag{4}$$

$$R = C_{min}/C_{max} \tag{5}$$

Number of transfer units,

$$N = UA/C_{min} \tag{6}$$

where A is heat transfer area of heat exchanger.

$$E = 1 - \exp\ [\{\exp\ (-RNn)-1\}/Rn] \tag{7}$$

where $n = N^{-0.22}$

$$E = \frac{C_g\ (T_{g\ in} - T_{g\ out})}{C_{min}\ (T_{g\ in} - T_{a\ in})} \tag{8}$$

The following iteration method is used for heat exchanger calculations.

4. Initialize the value of $T_{g\ out}$ and calculate properties of gas.

5. Using equation (1) calculate the value of air flow rate (m_a).
6. Knowing the flow and thermal properties of air and gas and geometry of heat exchanger, calculate the heat transfer coefficients on air (h_a) and gas (h_g) side.
7. Using equation (2) the overall heat transfer coefficient (U) can be determined.
8. Effectiveness (E) of the heat exchanger can be calculated using equations (3) to (7).
9. Substituting the value of effectiveness in equation (8) obtain a new value of $T_{g,out}$.
10. Repeat the procedure till the assumed and calculated value of $T_{g\ out}$ agree.

Calculation of Dryer Capacity:

For curing of a particular cash crop it is necessary to control the air temperature and air flow velocity inside the curing chamber. Under forced flow conditions the time required for drying T_d can be calculated by applying heat and mass transfer equations. Dryer capacity can be determined by using following equation [36].

$$W = \frac{m_a\ (1 - M_f)\ (W_f - W_i)\ T_d}{(M_i - M_f)} \qquad (9)$$

where M_i and M_f are initial and final moisture content of the cardamom on wet basis. W_i and W_f are initial and final specific humidity of air.

Overall efficiency of the system (combined efficiency of furnace and heat exchanger) can be calculated as

$$\text{Overall efficiency} = \frac{C_a\,(T_{a\ out} - T_{a\ in})}{\text{Power Input}}$$

where Power Input = Burning rate of fuel (kg/hr) x calorific value of fuel (kWh/kg)

The predicted performance curves of the drying system are shown in Figs. 4.3 to 4.6 for cardamom. Figs. 4.3 and 4.4 show the capacity of the dryer in terms of green cardamom and overall efficiency of the system as a function of excess air factor for a particular size (0.75 m) of heat exchanger under different input power rating. Similarly the performance of the system at a particular input power rating of the furnace for different sizes of the heat exchanger is shown in Figurs 4.5 and 4.6.

4.2 Fabrication of the First Prototype Unit

Fabrication and assembling of one prototype unit consisting of furnace, plate-fin type cross flow heat exchanger and small wooden cabinet dryer was done at TERI for testing the viability of the system, to get preliminary data about thermal efficiency on the basis of which system can be modified for second prototype unit for field testing. During fabrication of this unit main consideration was to make it simple and easy to fabricate (which can be fabricated at any small fabrication workshop in any district level city easily) which will suit to rough handing in rural application.

4.2.1 Furnace

Furnace is fabricated with mild steel for first prototype unit (See Fig. 4.7). Provision is made to control the primary as

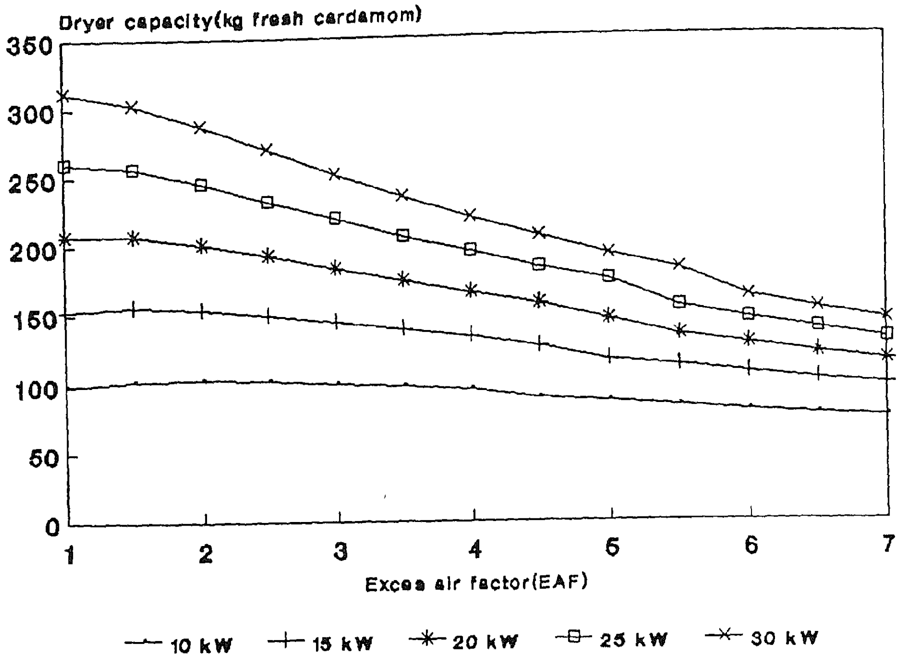


Fig. 4.3 System performance for different power input
(Dryer capacity for L = 0.45 m)

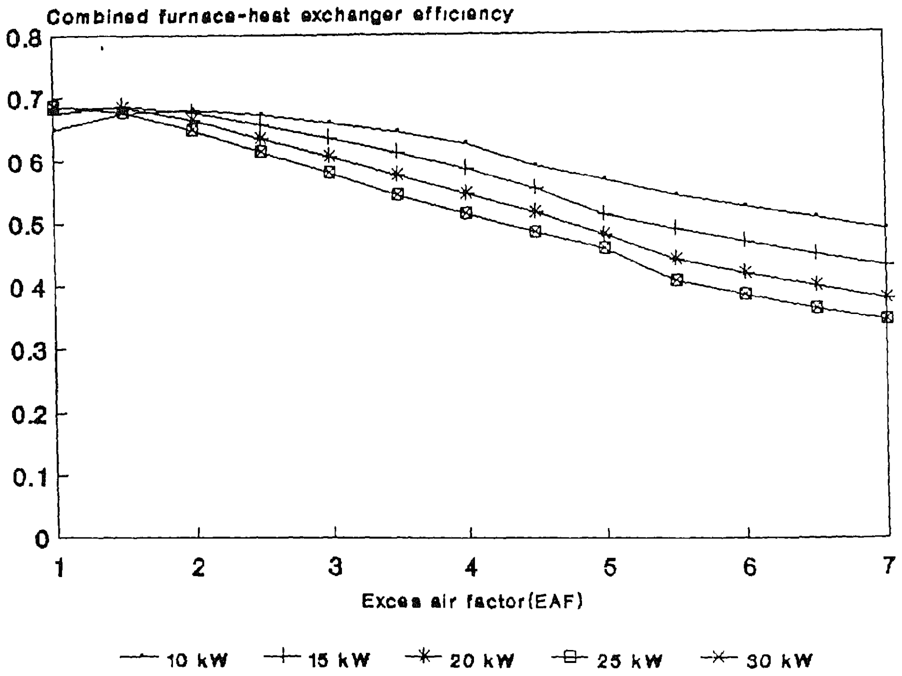


Fig. 4.4 System performance for different power input
(combined furnace-heat exchanger efficiency for L = 0.45 m)

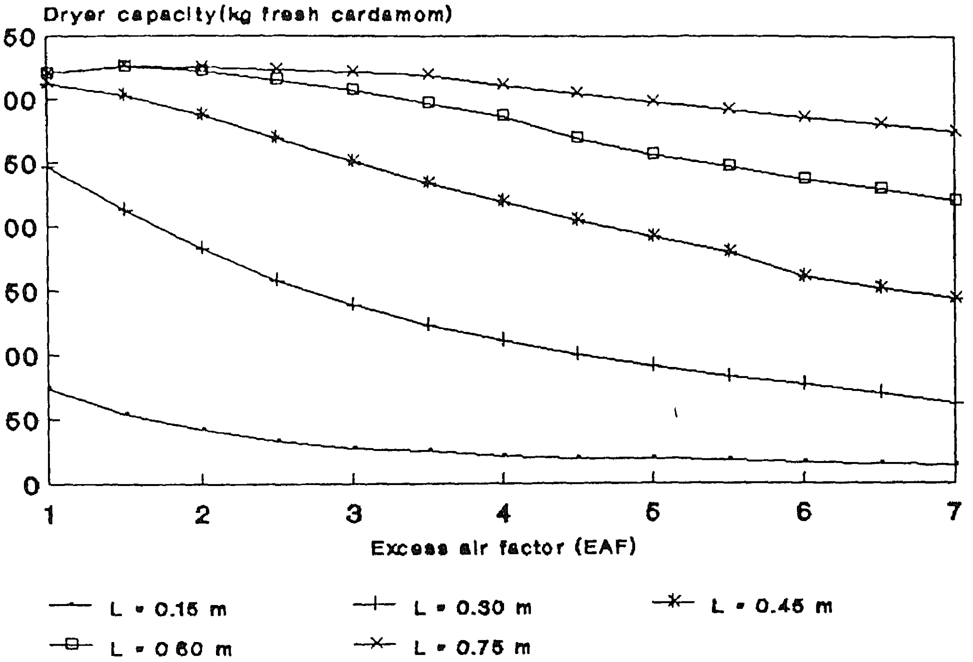


Fig. 4.5 System performance for various heat exchanger sizes (Dryer capacity vs. EAF for 30 kW power input rating)

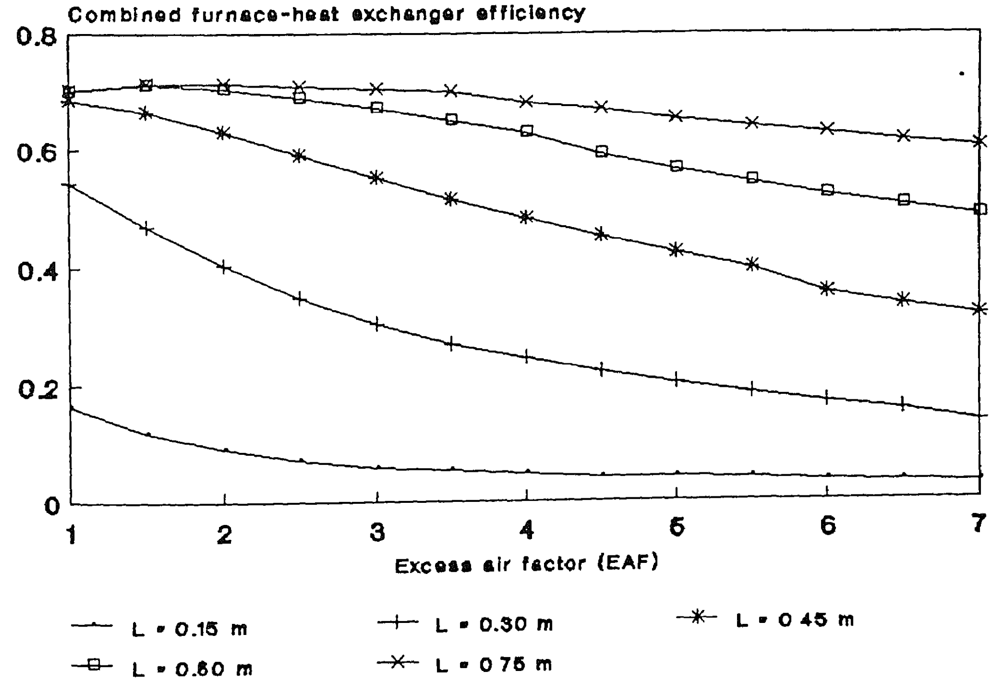


Fig. 4.6 System performance for various heat exchanger sizes (combined efficiency vs. EAF for 30 kW power input rating)

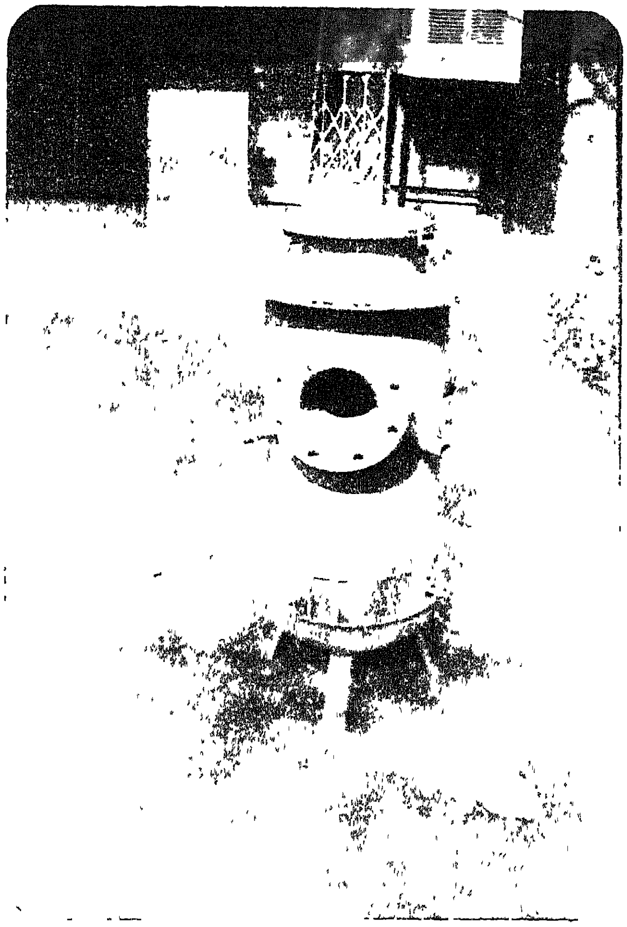


Fig. 4.7 Furnace without insulation

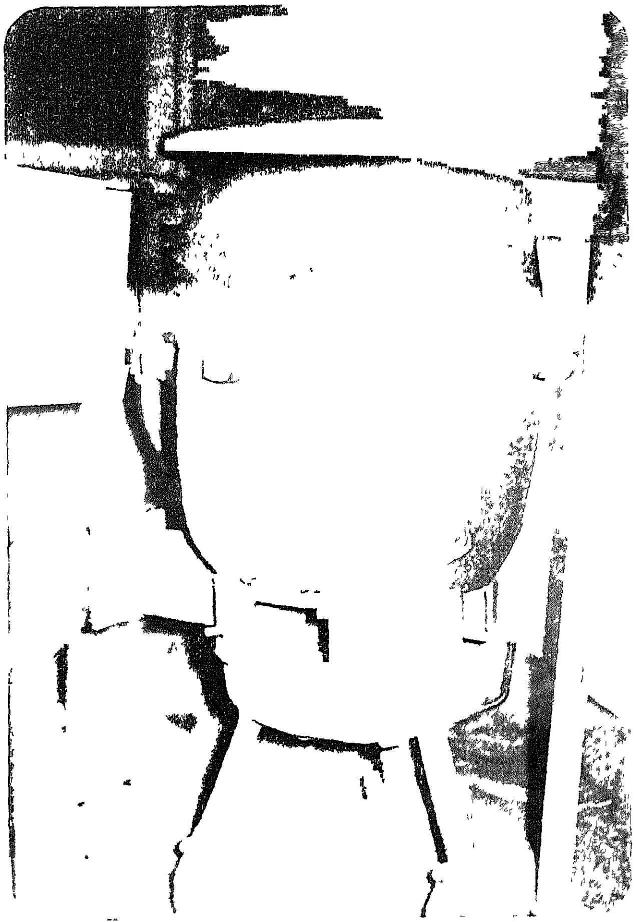
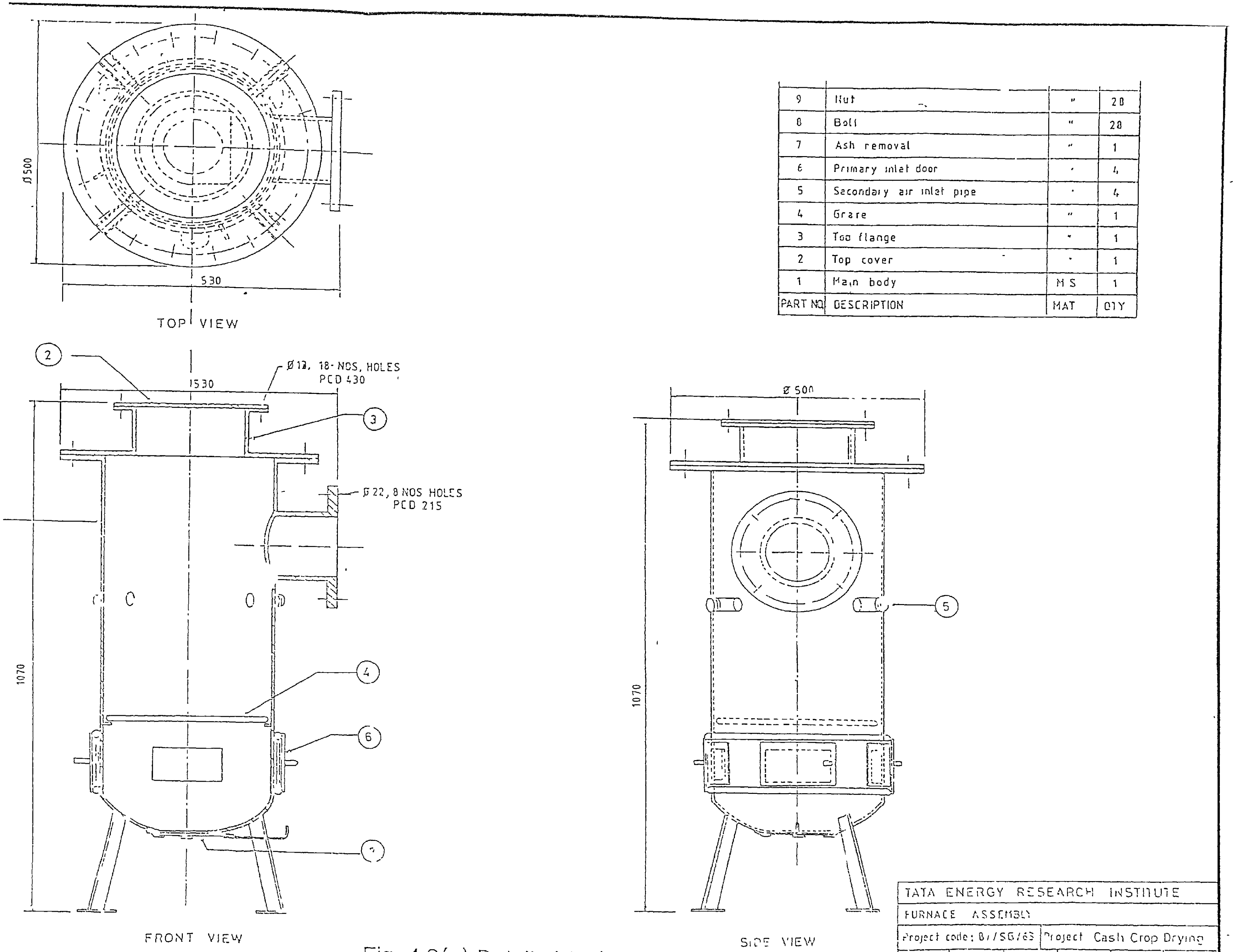


Fig. 4.8 Furnace with insulation



PART NO	DESCRIPTION	MAT	QTY
9	Nut	"	28
8	Bolt	"	28
7	Ash removal	"	1
6	Primary inlet door	"	4
5	Secondary air inlet pipe	"	4
4	Grate	"	1
3	Top flange	"	1
2	Top cover	"	1
1	Main body	M S	1

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Fig. 4.9(a) Detailed technical drawing of furnace (Assembly)

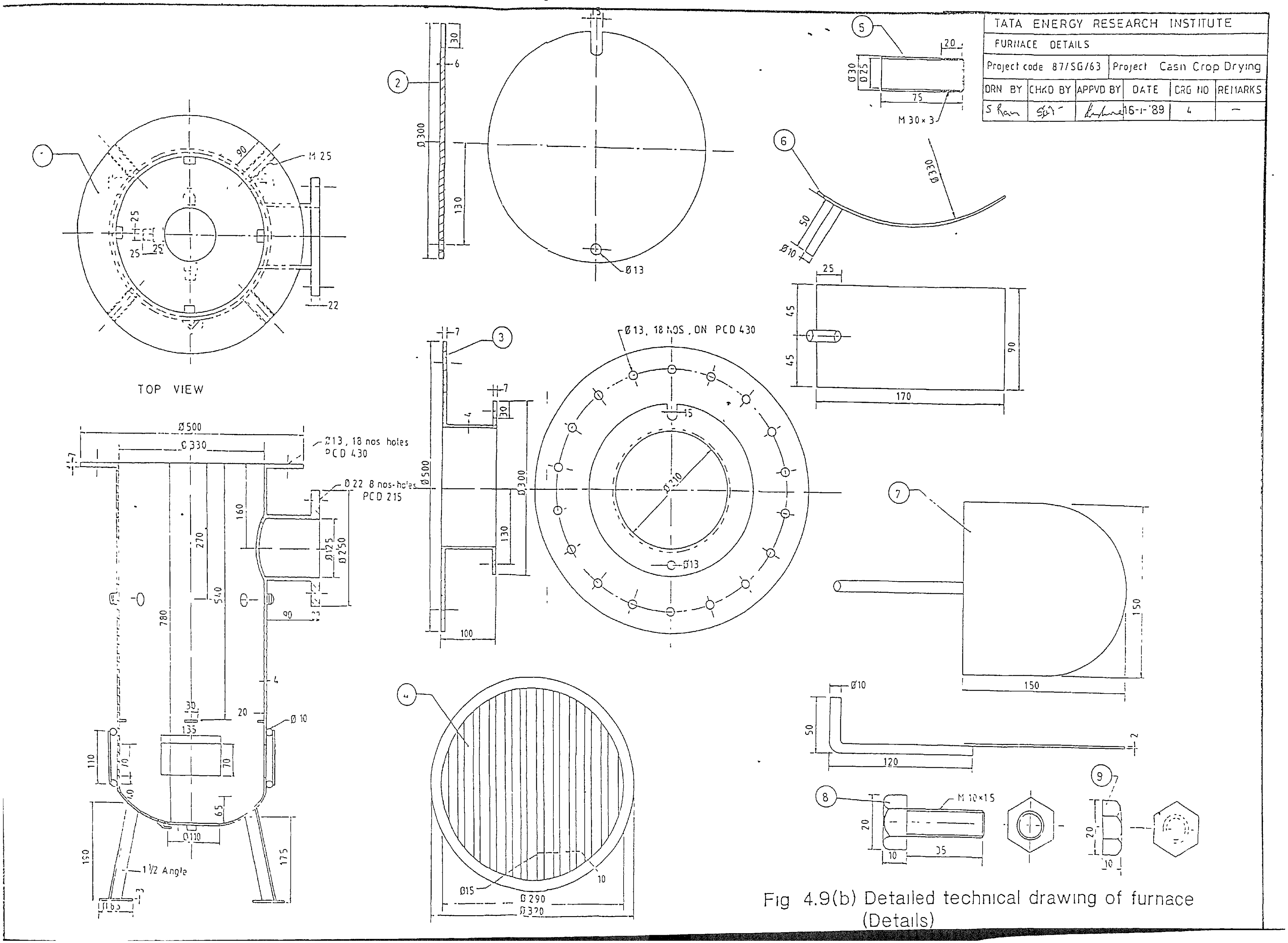

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Fig 4.9(b) Detailed technical drawing of furnace (Details)

well as secondary air supply. Furnace is designed so as to suit it for operation under different power rating upto 30 kW Dimensions are calculated for different power rating using following empirical equations [33] and optimum value is taken.

Grate area	50 W/cm^2
Combustion volume	0.60 lit/kW

In order to minimize the heat loss the furnace is insulated with 3 inch thick layer of super-crete insulation (See Fig. 4.8). Before that nails were welded to furnace to provide reinforcement for insulation. Four sliding doors were provided to control the primary air supply. Provision is made to control secondary air supply also if necessary. For this purpose MS pipe union is welded to furnace walls in which pipe closers with varying diameter hole drilled into it can be fitted to control secondary air supply above fuel bed inside the furnace. The detailed technical drawing of the furnace is shown in Fig. 4.9 (a&b).

4.2.2 Heat Exchanger

For the first prototype unit the plate-fin type cross-flow (both fluids unmixed) is fabricated from cheap material such as G.I. sheets. The schematic diagram of heat exchanger is shown in Fig. 4.2. As said earlier the main consideration given during fabrication is to make the system simple and easy for fabrication. Since heat transfer is taking place from gas to air and knowing the fact heat transfer coefficient for gaseous fluid is very low compared to liquids it was decided to go for plate-fin type heat exchanger since they provide much more heat transfer area within same volume of heat exchanger. Since the hot air temperature required is not very high compared to gas inlet temperature, cross flow arrangement for fluid flow within the heat exchanger is selected instead of the more efficient counter flow pattern.

Considering this the heat exchanger is fabricated as a cube of length L = 0.75 m. For the first prototype unit available ready-made GI corrugated sheets are used as plate fin to make the fabrication simple (See Fig. 4.10). Otherwise aluminium sheets with different profile (such as triangular, squares, trapezoidal etc.) can be used instead of GI sheets. The detailed technical drawing of heat exchanger of the first prototype unit is given in Fig. 4.11 (a&b). While assembling heat exchanger corrugated sheet are stacked one above other with corrugation of right angle in consecutive layer. Plain GI sheet is provided between two consecutive corrugated sheets to keep air and gas streams unmixed. Two corrugations at each end which are going inside corner angle of the heat exchanger are filled with insulating material to prevent any leakage of gas at the corners. All the sheets are assemble inside MS angle making it a compact box which can be transported easily.

4.2.3 Cabinet Tray Dryer

As can be seen from the predicted performance curves of the system the hot air available with this furnace and heat exchanger is sufficient to dry approximately 400 kg of wet cardamom. to get the preliminary data on drying of crop under forced flow conditions on air side it was decided to dry small quantity of crop and to study the thermal performance of furnace and heat

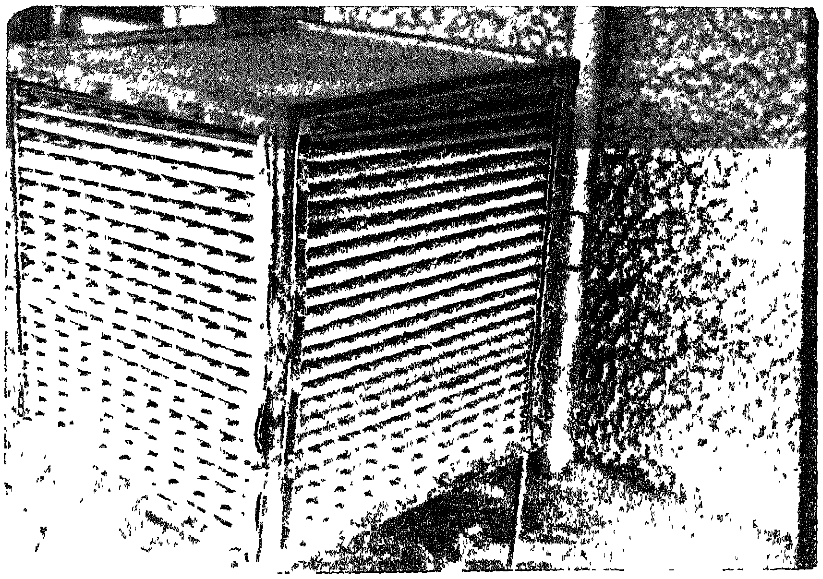


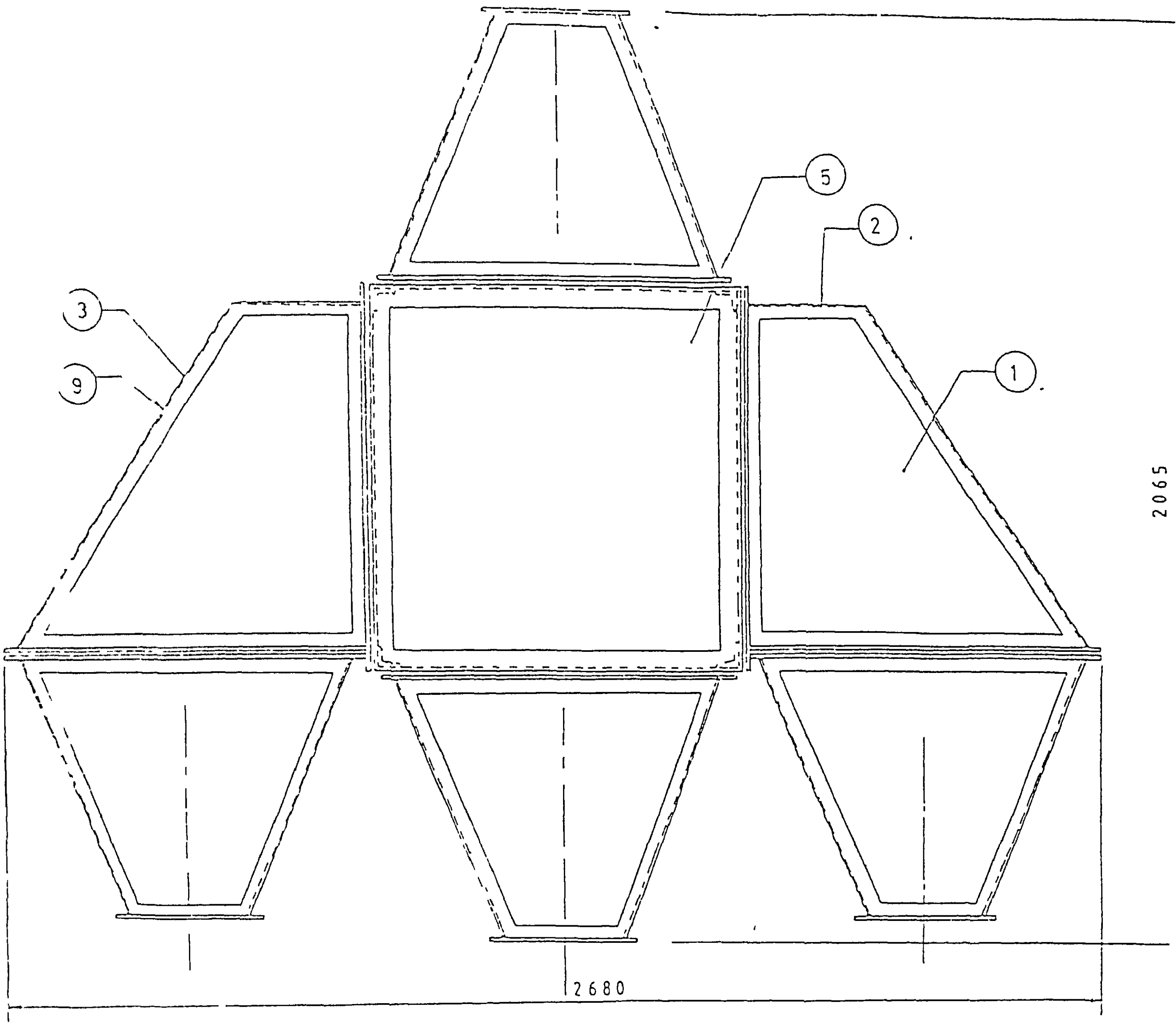
Fig. 4.10 Cross flow plate-fin heat exchanger

exchanger. So a wooden cabinet tray dryer was fabricated at TERi which can accommodate 10kg of fresh product (See Fig. 4.12). The detailed technical drawing of the dryer is shown in Fig. 4.13. In this dryer 18 trays of size of 3" x 15" can be accommodated. Trays are prepared with aluminium angles and with perforated SS wiremesh so that maximum surface area of the product is exposed to hot air. Air flow within the dryer is parallel to the trays in which product is spread in mono layer.

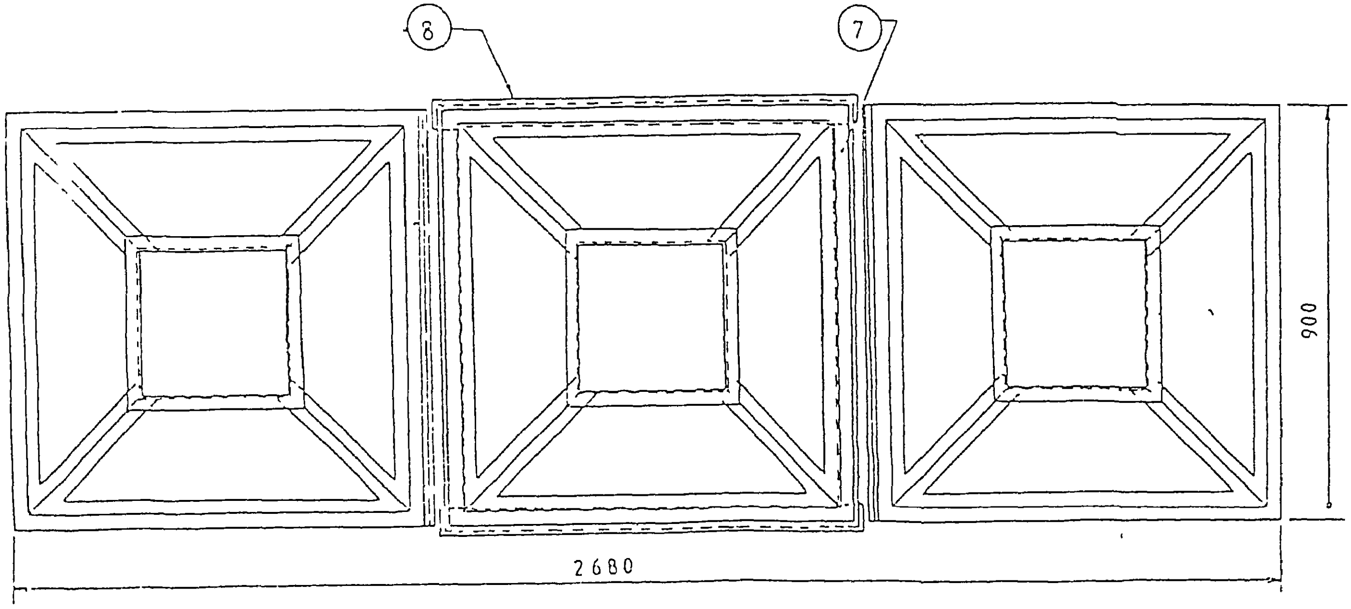
4.3 Assembling of the Prototype Unit

All the components of the first prototype drying unit are assembled at TERI. Photographs in Figs. 4.14 and 4.15 show the overall view of the first prototype unit assembled at TERI from two sides to show all the components. Coal (fuel) is fed into the furnace. The hot flue gases are passed through the heat exchanger and then thrown out throu chimney. The heat is transferred to the air which is forced in the heat exchanger with the help of blower. Hot air available at the outlet of heat exchanger is passed over the trays in the cabinet tray dryer. The furnace is operated on the natural draft. Provision in the ducting was made (i) to run the furnace on forced draft by passing part of the cold air through furnace (ii) to recirculate part of dryer exhaust through furnace.

Arrangement is made to vary the air flow rate. Thermocouples were installed at many places to measure temperature of gas and air at many points in the heat exchanger, dryer, chimney to evaluate thermal performance of the system.



TOP VIEW



FRONT VIEW

9	Plain sheet for bend	G I	1
8	Heat exchanger square frame	MS	2
7	Heat exchanger side angle	MS	4
6	Duct frame	MS	4
5	Plate fins plain & corrugated	G I	16
4	Plain sheet for duct	G I	16
3	Gas side bend, frame	MS	2
2	Plain sheet for bend	G I	1
1	Plain sheet for bend	G I	4
Part no.	Description	Material	Qty

TATA ENERGY RESEARCH INSTITUTE					
PLATE FIN CROSS FLOW HEAT EXCHANGER ASSEMBLY					
Project code 87/SG/63		Project Cash Crop Drying			
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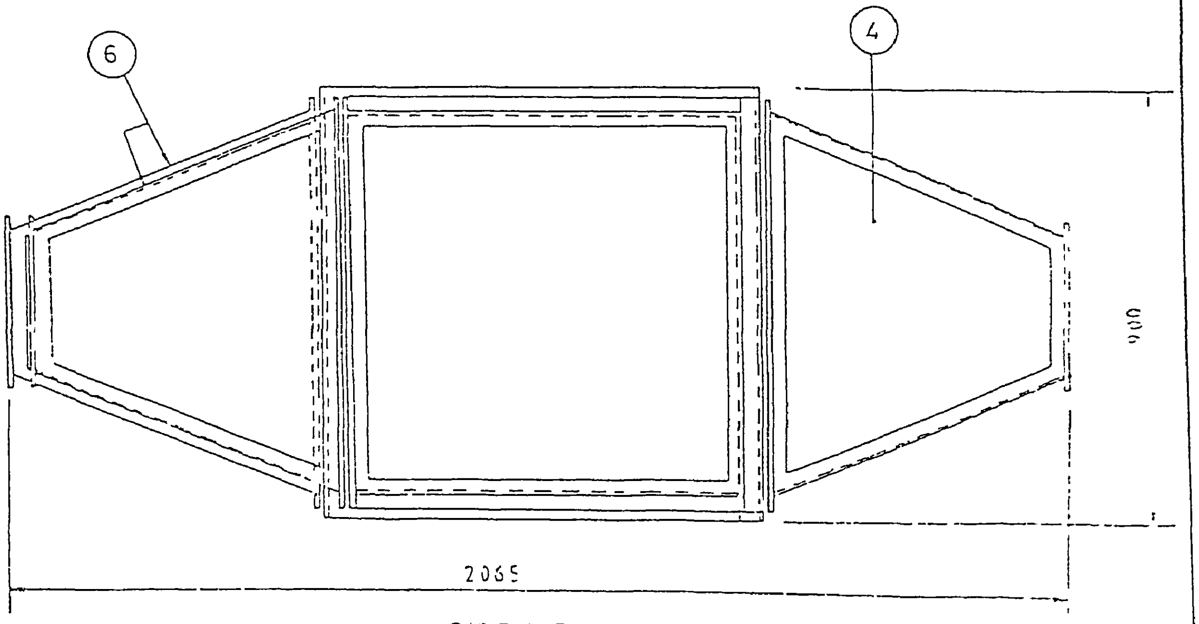
S Ram			12-1-89	1	–

Fig 4.11(a) Detailed technical drawing of heat exchanger (Assembly)



SIDE VIEW

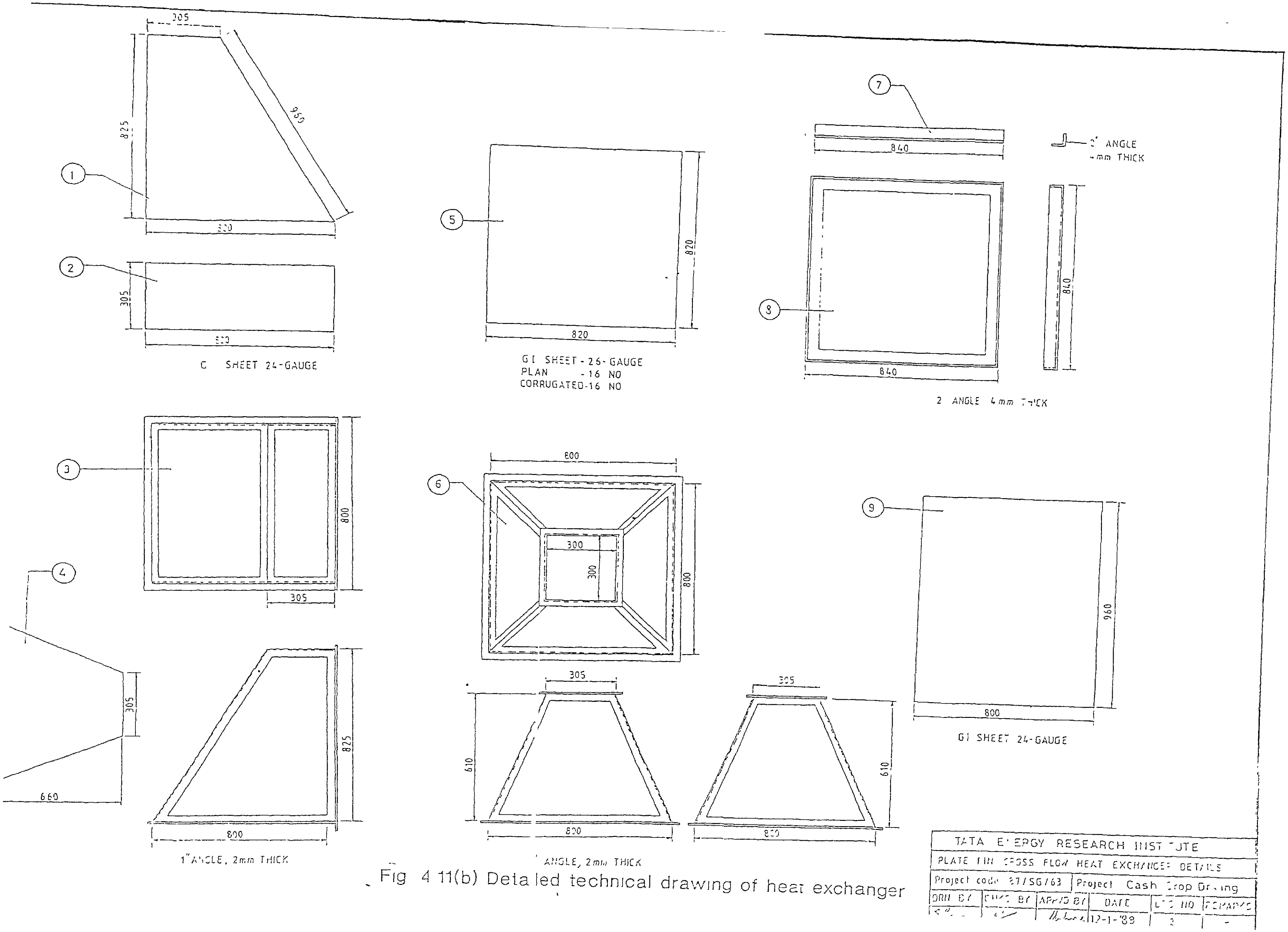


Fig 4 11(b) Detailed technical drawing of heat exchanger

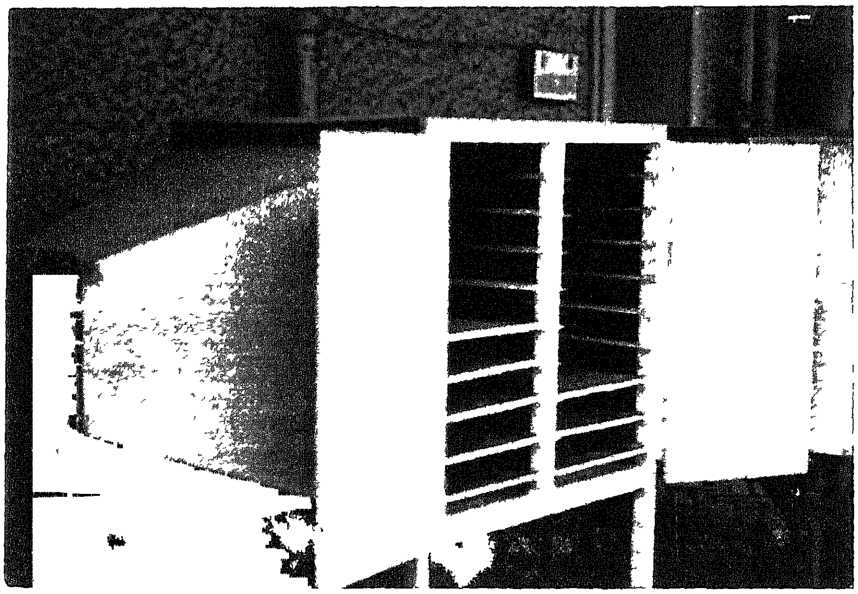
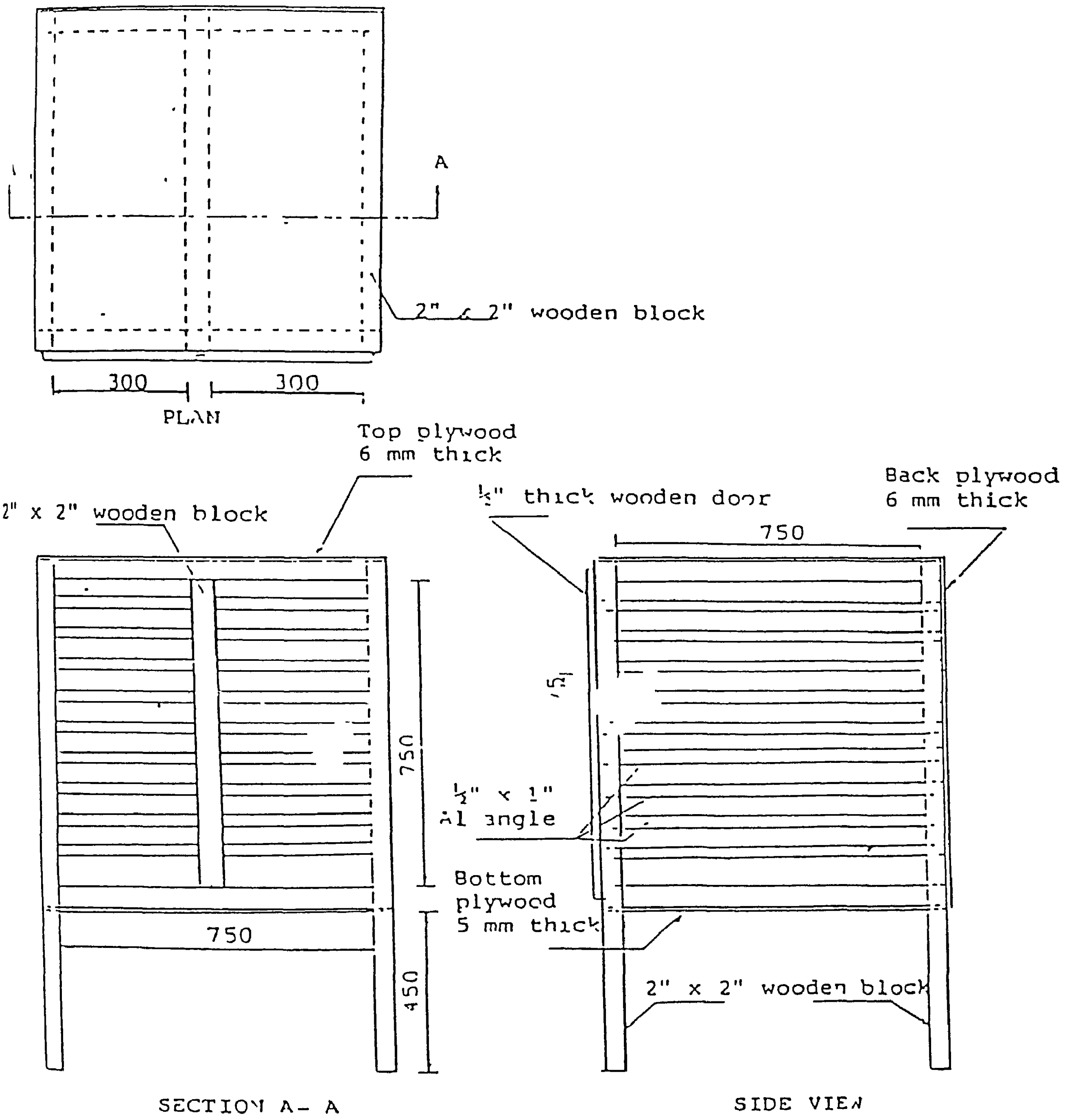


Fig. 4.12 Cabinet tray dryer



g. 4.13 Cabinet tray dryer - technical details

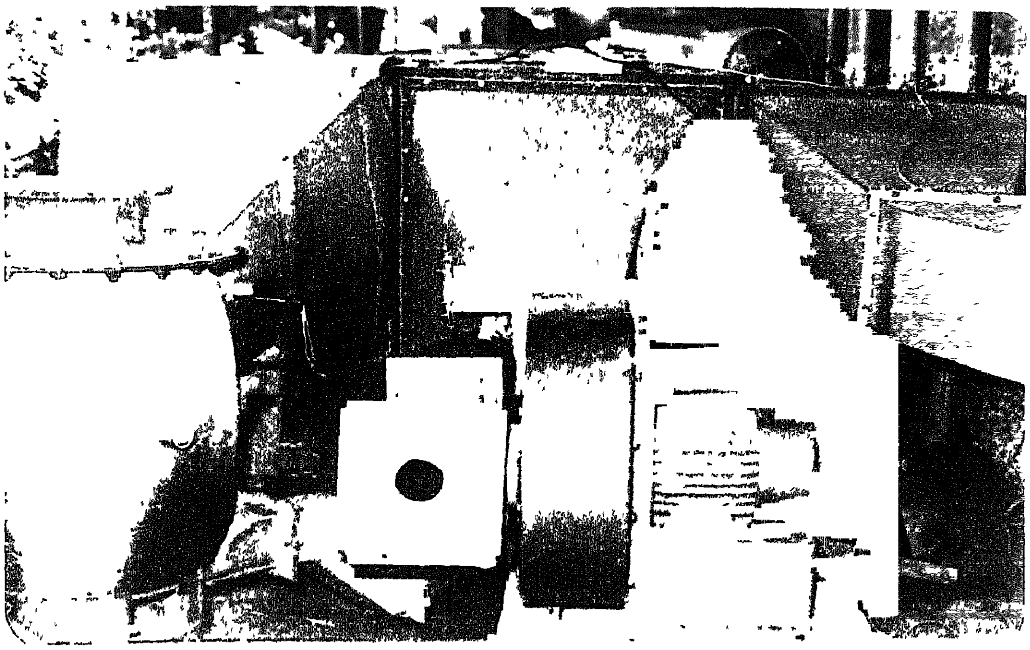


Fig. 4.14 Complete view of first prototype unit from furnace side

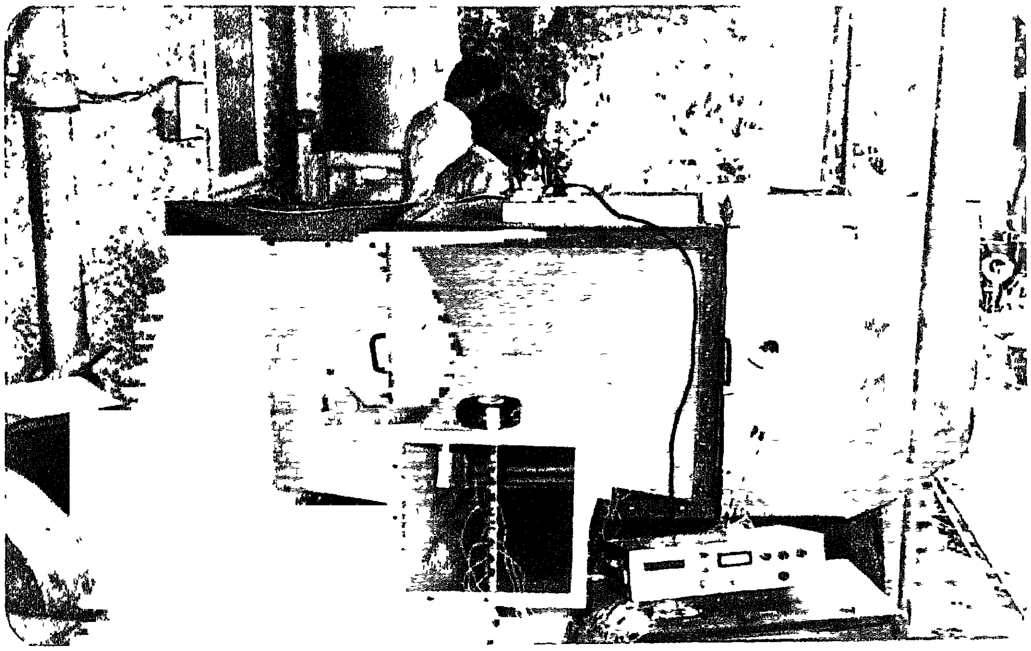


Fig. 4.15 Complete view of first prototype unit from dryer side

5. PERFORMANCE TESTING OF THE FIRST PROTOTYPE UNIT

After assembling the first prototype unit at TERI as described in the previous section, trial runs were conducted to study the performance of the complete system. The objective was to check for any leakage, mixing of flue gases with the air supplied to dryer, temperature and flow distribution etc..

5.1 Details of Trial Runs

During trial runs it was observed that there was leakage of flue gases at the corner of the heat exchanger causing mixing of flue gases with air going into the dryer. In order to overcome this problem the two end corrugations of the plate fin sheet were filled with cotton. But this could not stop the leakage since at higher flue gas temperatures, cotton got charred. Then fire clay was tried instead of cotton waste. This solved the problem of leakage but since in long run there is a possibility of loosening of fire clay it was decided to use ceramic fibre insulating material, which besides being flexible, can also withstand, up to 1260°C. The sample of air going into the dryer was analyzed temperatures using an Orsat apparatus and it was found that there was no leakage of flue gases to a noticeable level using Orsat gas analyser. This was also confirmed using CO, CO_2 monitor.

In order to use only one blower for the drying system and to control the burning rate it was decided to bypass part of the air going into the heat exchanger to the furnace in order to have forced draft operation of furnace for achieving higher burning rate. To achieve this, one duct was fabricated connecting main duct carrying air to the heat exchanger to the inlet of the furnace. Schematic diagram of the arrangement is shown in Fig. 5.1. During trial runs it was observed that instead of supplying the air to the furnace there is a flow of air from furnace to heat exchanger. This was confirmed by measuring pressure at different locations in the ducts with the help of a U-tube manometer. The reason for this may be the ejector action occurring at the T-joint between branch duct and main air duct connecting blower and heat exchanger. The large quantity of air with higher momentum which is flowing through the main duct creates a low pressure zone at T-joint and sucks the air through bypass duct i.e. from furnace. This phenomenon is predominant when fuel bed height inside furnace is lower. Hence it was decided to operate the furnace on a natural draft mode.

Another problem faced during the trial on first prototype unit was uneven distribution of gas inside the heat exchanger, since hot flue gases, due to natural tendency, were raising to the top portion of the heat exchanger. To overcome this problem one baffle was introduced to direct the hot flue gases coming out of the furnace, towards the bottom side of the inlet of heat exchanger. At the end of the baffle, an SS wiremesh was placed to create turbulence in the flue gas flow (See Fig. 5.2). This minimised the nonuniformity to some extent. Since the area available for heat loss was large in the inlet duct the temperature of the gas at the inlet of heat exchanger was very low which was the reason for very low temperature of air inside dryer. To overcome this problem to some extent, a small size flue gas duct was used and this time it was connected to hea

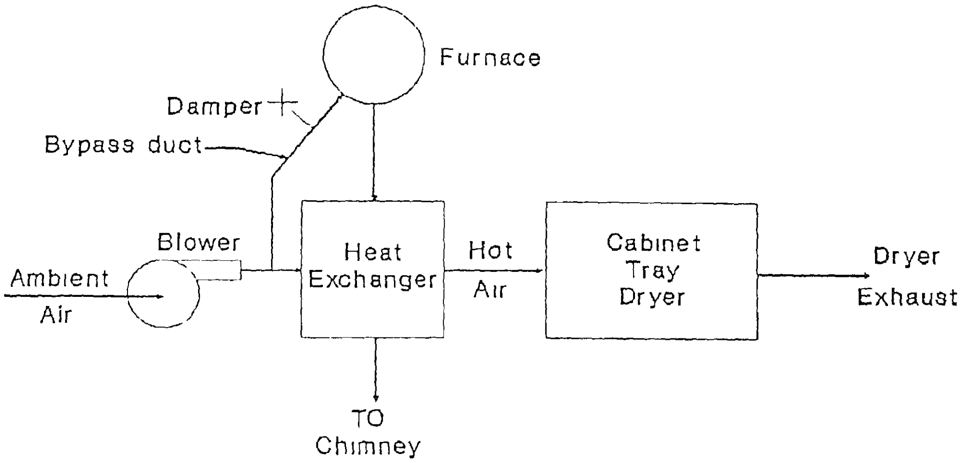


Fig. 5.1 Bypass duct provided for air supply to furnace

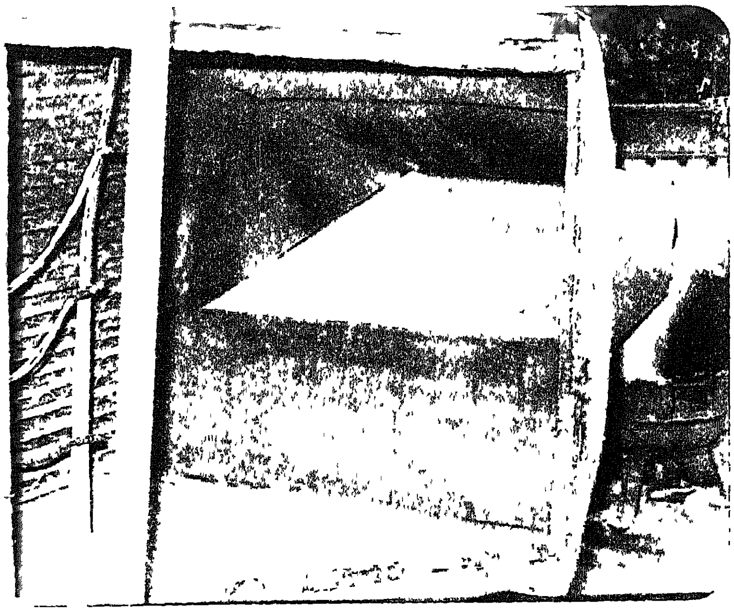


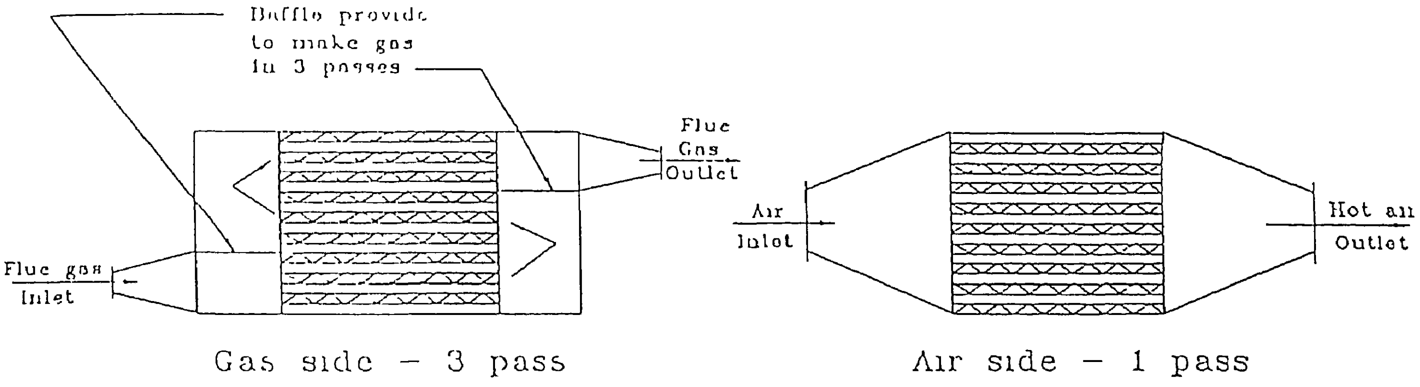
Fig. 5.2 Baffle arrangement for gas at the inlet of heat exchanger

exchanger header from bottom making the use of baffle unnecessary. After incorporating this modification it was decided to use three passes on flue gas side which make the flue gases to travel more distance inside the heat exchanger by introducing two partitions in the gas header of the heat exchanger as shown schematically in Fig. 5.3. This helps in extracting maximum amount of heat from the flue gases and to improve the thermal efficiency.

Afterwards it was decided to recirculate the hot dryer exhaust to the furnace which will result in some energy saving and also helps to accelerate burning rate of fuel inside furnace. For this purpose, duct was fabricated connecting dryer exhaust to furnace air inlet (See Fig. 5.4). This arrangement worked satisfactorily.

5.2 Peas Drying

After rectifying the system to overcome the problem faced during the trial runs in order to study the effect of forced flow methods in the dryer it was decided, as suggested by Dr. V. Govindarajulu of UPASI, Vandiperiyar, to dry peas since peas drying is similar to cardamom drying in some respects such as moisture content levels and maintaining green colour. The performance of the system was found to be satisfactory indicating that the forced flow methods and improved heat exchanger design can lead to better thermal performance and reduced drying time. The weight loss curves for peas drying for a few experimental runs are shown in Figs. 5.5 to 5.7. This shows that to reduce the weight of fresh green peas to 25-30% of its initial weight it



Gas side – 3 pass

Air side – 1 pass

Plate-fin cross flow heat exchanger

Fig 5 3 Baffle arrangement for 3-gas pass in heat exchanger

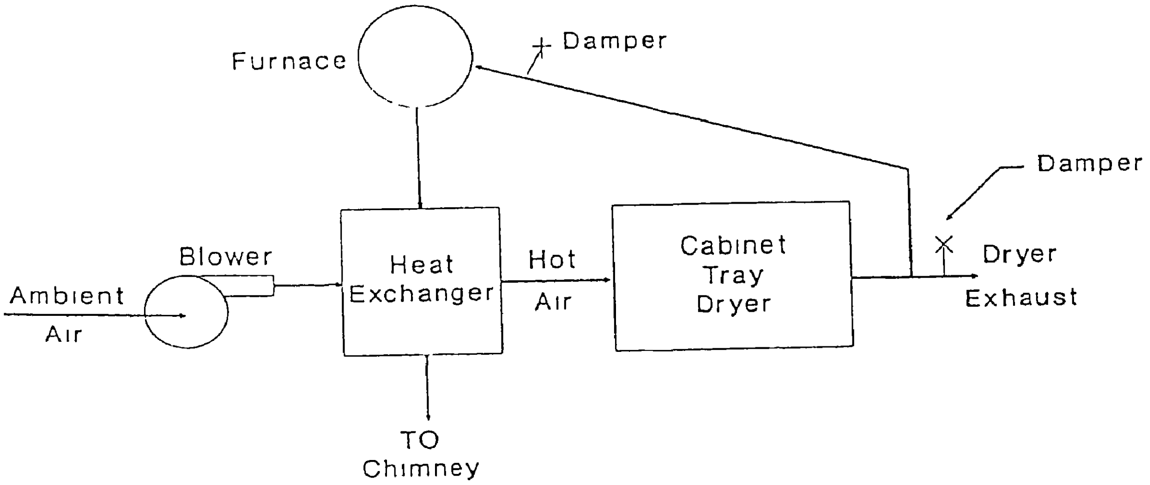


Fig 5 4 Arrangement for recirculation of dryer exhaust

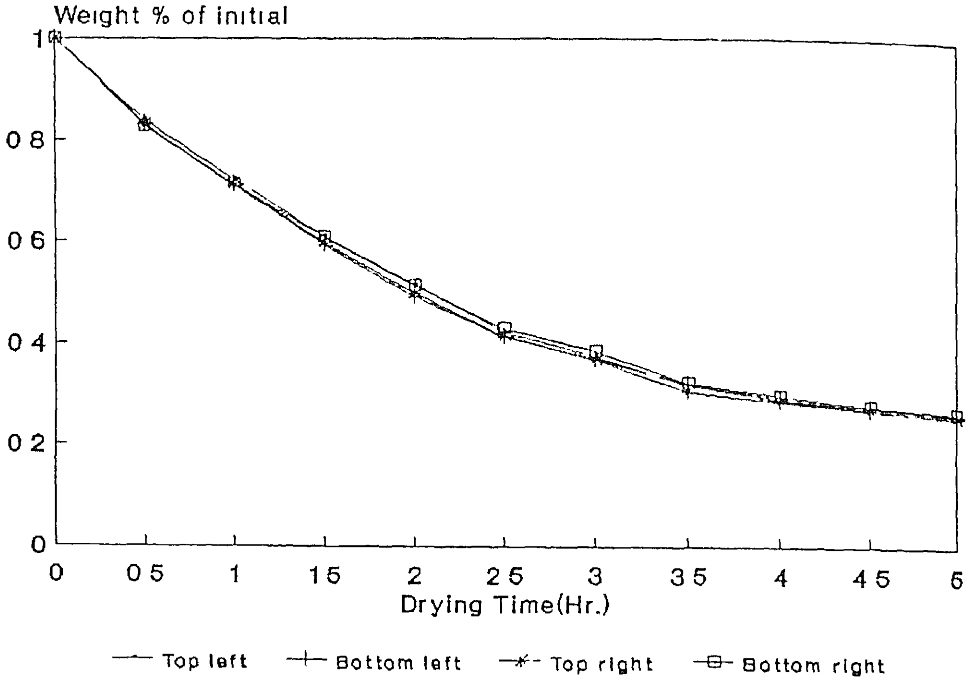


Fig. 5.5 Peas drying (August 31, 1990)

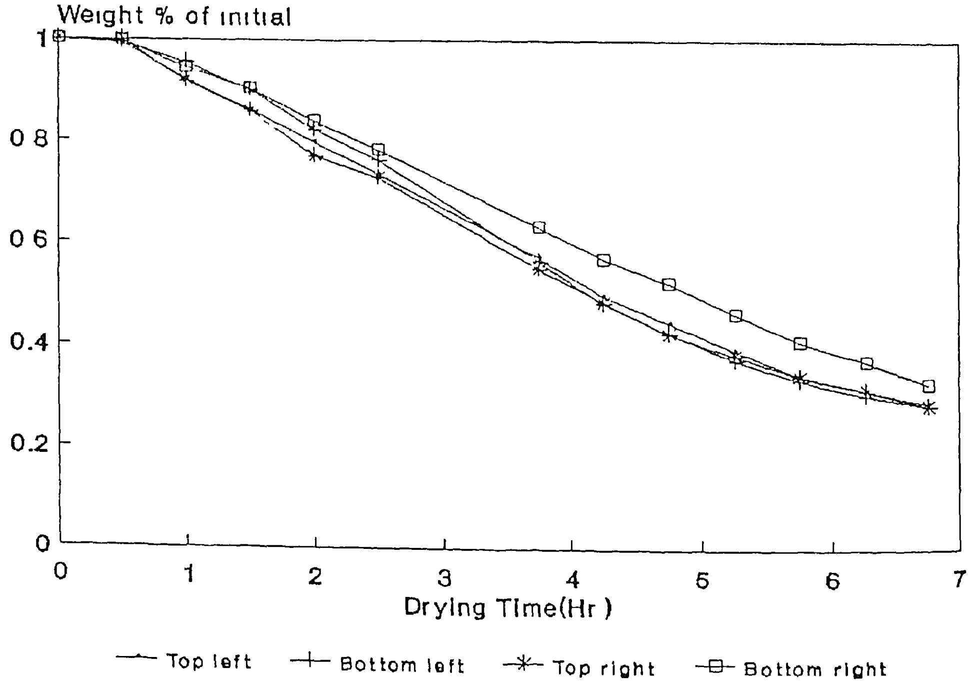


Fig. 5.6 Peas drying(September 10, 1990)

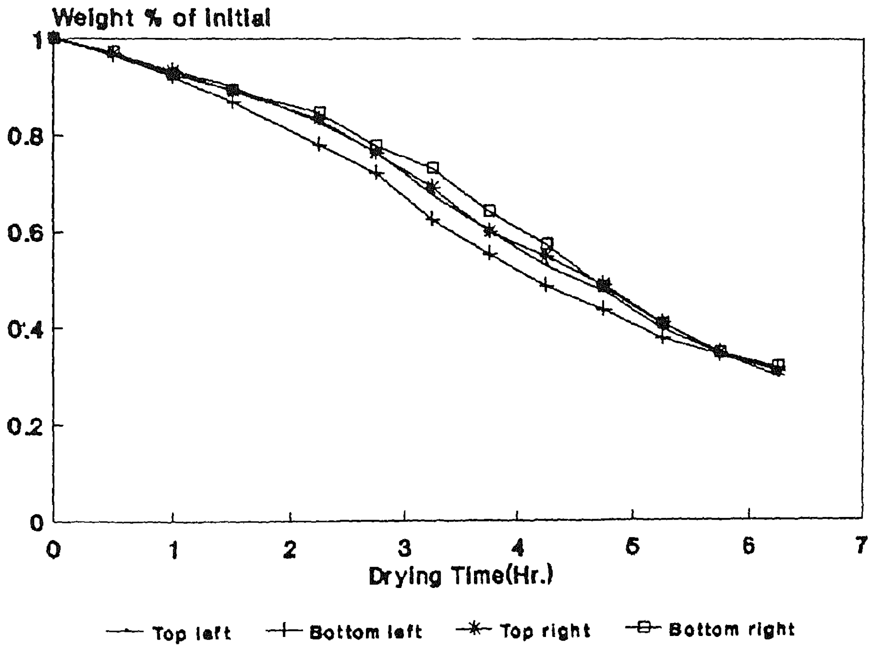


Fig. 5.7 Peas drying (September 11, 1990)

takes 5-7 hours. The thermal analysis of the system to find effectiveness of the heat exchanger was done. The detailed analysis of the data collected is given in Table 5.1.

Table 5.1 Peas Drying experimental data analysis

Date	Fuel used (kg)	Total Time (hrs)	T_{ain} (°C)	T_{aout} (°C)	T_{gfo} (°C)	T_{gin} (°C)	T_{gout} (°C)	V_{ain} (m/s)	M_{air} (kg/hr)	Q_{air} (kcal/hr)	Q_{fuel} kcal/hr	M_{gas} kg/hr	Heat Exchanger Effectiveness	Furnace Efficiency
30-08-90	26.0	8	31.2	52.2	512	190.8	58.4	3.52	330.66	1673.48	13000	49.077	0.830	0.467
31-08-90	23.4	9	32.5	51.1	563	257.3	57.1	4.13	385.85	1729.59	10400	33.259	0.891	0.441
10-09-90	26.0	9	29.6	48.6	572	215.0	56.9	4.84	457.06	2092.90	11556	51.246	0.853	0.621
11-09-90	20.1	8	31.0	49.4	468	191.6	57.5	3.47	325.71	1444.33	10050	41.820	0.835	0.468
24-09-90	21.5	8	30.8	46.7	531	230.4	54.5	4.95	465.61	1784.16	10750	39.199	0.881	0.472

Note:- 1. Fuel used is charcoal
2. The data given here are average values foreach experimental run.
3. Detailed procedure of data analysis is given in Annexure-II

Thus it seemed quite plausible to improve the overall energy efficiency and to reduce the drying time for cardamom using the prototype developed in this project. As trials on the various crops like cardamom can be done only at the field, it was decided to embark on field testing without further delay.

6. DESIGN AND FABRICATION OF THE SECOND PROTOTYPE DRYER

Based on the experience gained on the first prototype unit, modifications were made in the design of various components of the system in the second prototype unit which was fabricated for field evaluation of the system for drying some cash crops under actual field conditions.

6.1 Modifications Incorporated in the System

6.1.1 Furnace

In the first prototype unit the insulation of the furnace was from outside. This time it was provided from inside. The reason for this is that if the insulation is from outside the interface (metal) temperature goes up considerably, thus subjecting the furnace material to higher temperatures, which results in reduced life. Also the ceramic insulation provided on the outside, developed cracks on heating due to expansion causing damage to insulating material and causing heat losses through cracks. The photograph shown in Fig. 6.1 shows the furnace without insulation and Fig. 6.2 shows fire clay insulation of 3" thick applied from inside of the furnace.

Drying of cash crops is a continuous process continuing for several hours per batch. Thus there is a need to make provision for feeding fuel into the furnace without opening the top as was the case with first prototype unit. For this purpose, a hopper was provided with damper at the top of the furnace. Coal can be filled into the hopper and dropped into the furnace at regular intervals by just opening the damper. Figure 6.3 shows the close up of the top portion of the furnace showing hopper provided to

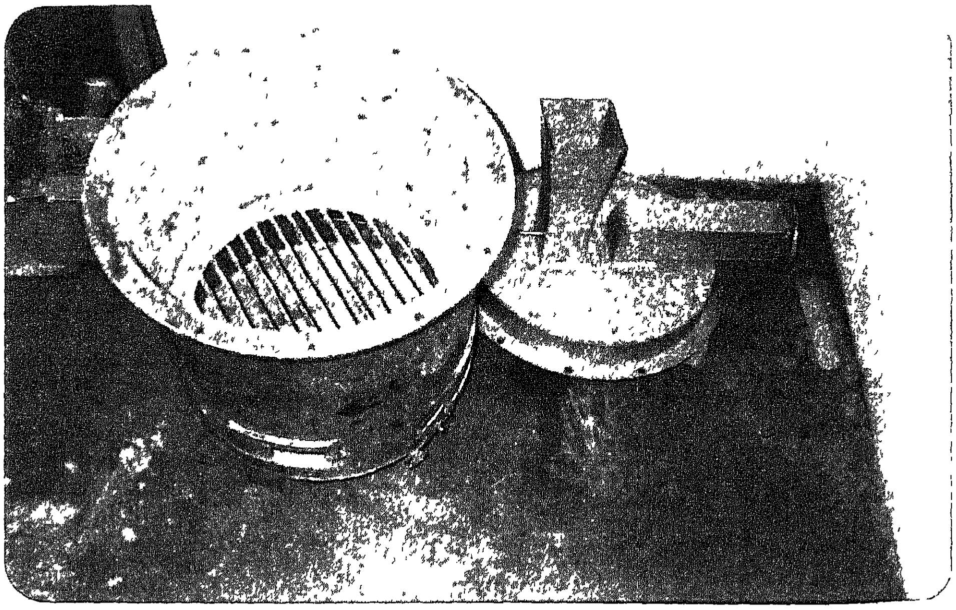


Fig. 6.1 Furnace before insulation

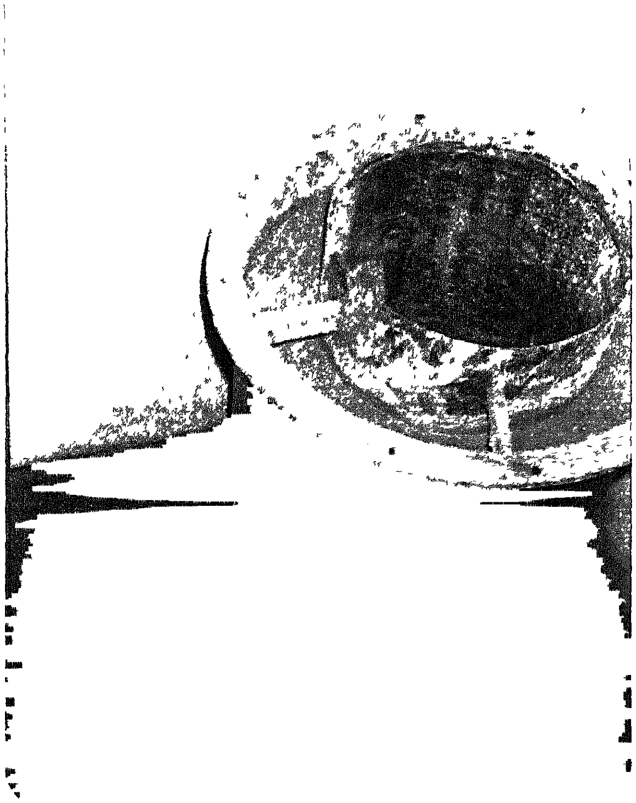


Fig. 6.2 Furnace insulated from inside

feed the coal at regular intervals and damper provided at furnace gas outlet to control the gas flow. The complete furnace is shown in the Fig. 6.4.

In the modified furnace four sliding doors are provided below grate level to control the primary air supply to the furnace. A lever mechanism was provided, as shown in Fig. 6.4, to make the operation easy. One damper is provided in the gas outlet duct from furnace which can be fixed at different positions in order to control the gas flow rate (See Fig. 6.3). During the start this gas outlet damper is kept in closed position and damper in the hopper is kept fully open till the fuel bed is ignited. This prevents soot and tar present during initial period of furnace operation from going into the heat exchanger which may settle there and block the passages in the heat exchanger.

The detailed technical drawing is given in Fig. 6.5.

6.1.2 Heat Exchanger

For the second prototype unit the heat exchanger design is modified to make it more efficient and compact. As stated earlier, ready-made GI corrugated sheets were used as plate-fins in the first prototype unit. In the second unit the profile of the plate-fin is changed from sinusoidal profile to square profile. The problem with GI corrugated sheet is that the profile of the sheet changes from one lot to the other lot. The profile gets flattened if the sheet is drawn more while making corrugations on it. The smaller the plate fin profile, the more

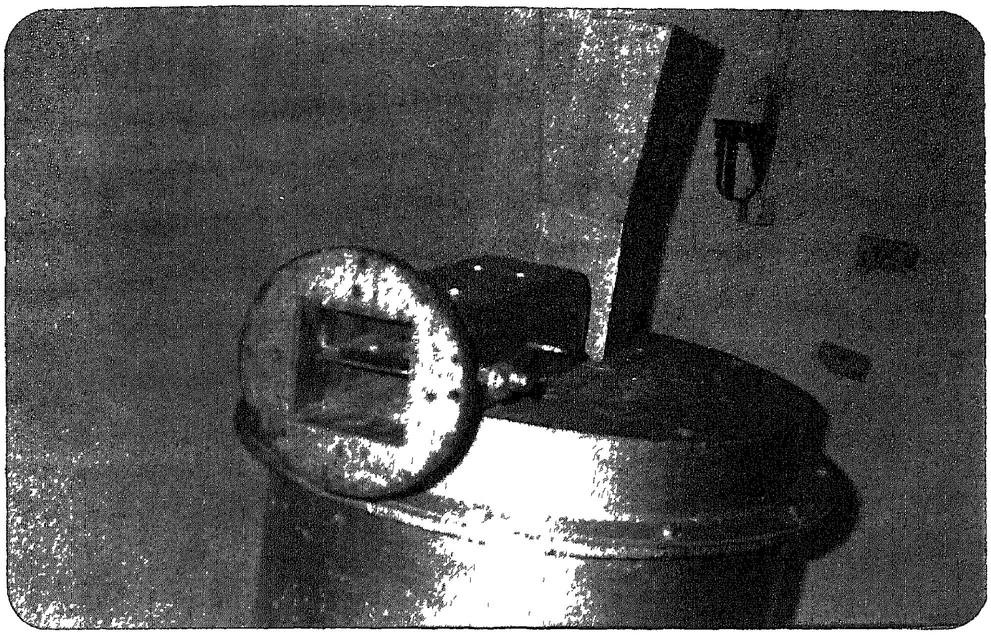


Fig. 6.3 Furnace showing hopper and gas outlet damper

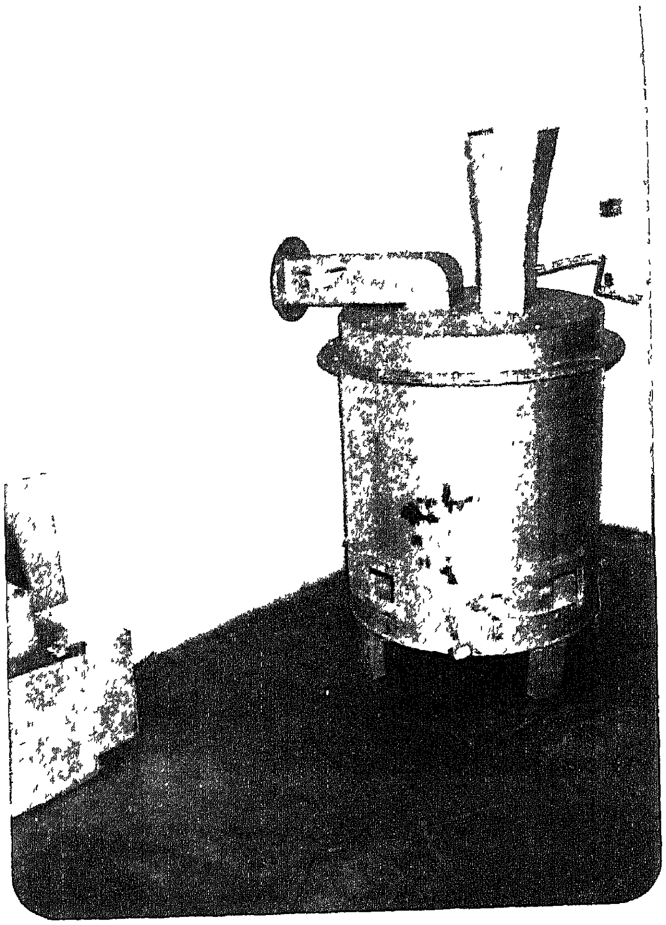
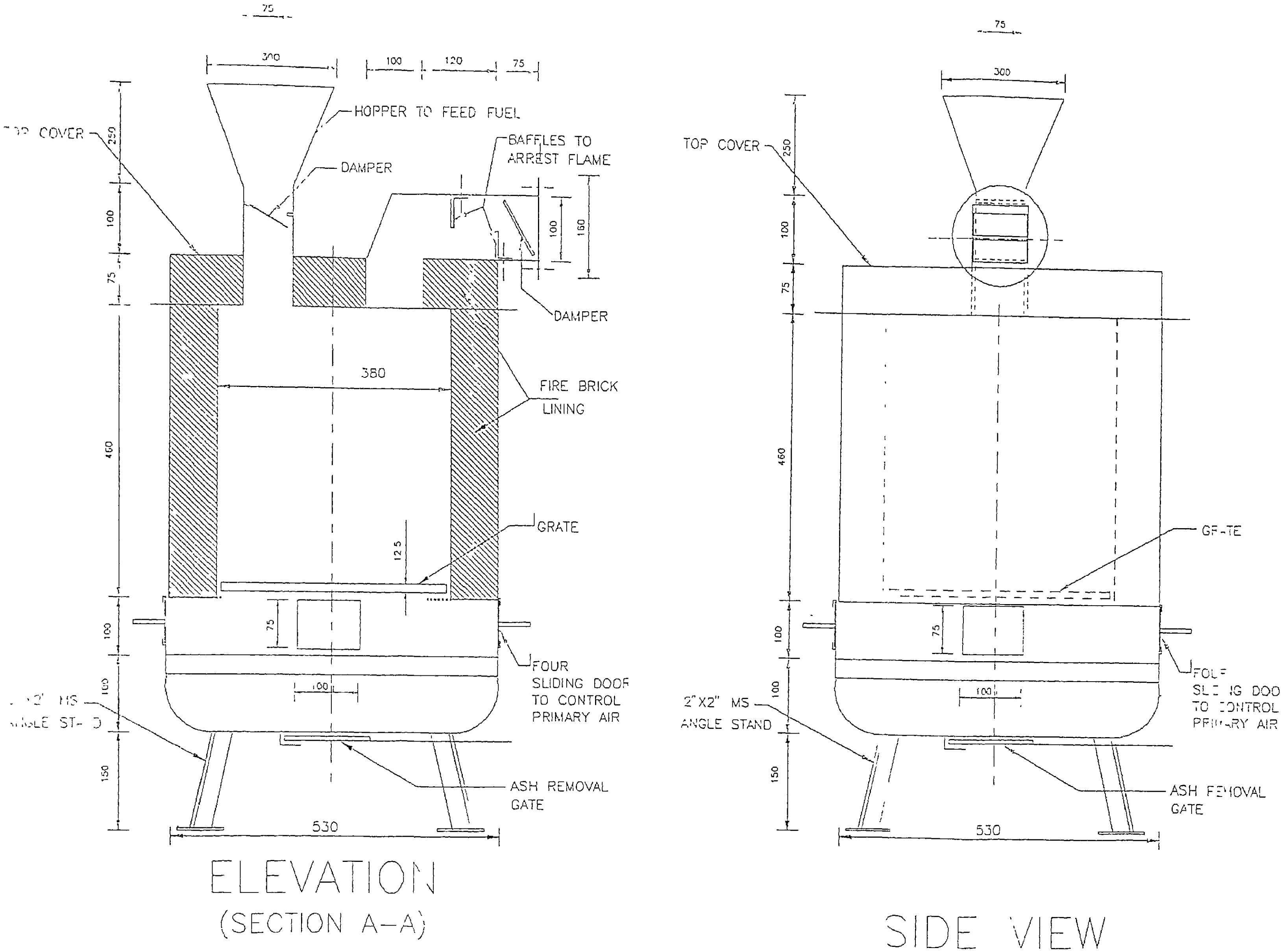


Fig. 6.4 Complete view of furnace



ELEVATION
(SECTION A–A)

SIDE VIEW

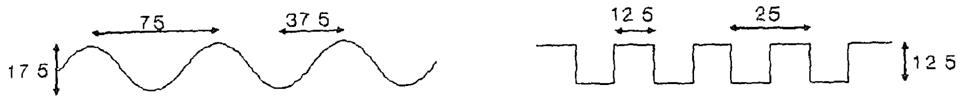
Fig. 6.5 Detailed technical drawing of furnace

is the heat transfer area available per unit volume of the heat exchanger, thus making the unit more compact. For the second prototype unit, a 1/2" x 1/2" square profile is selected. Table 6.1 gives details of both the profiles. It can be seen that the heat transfer area per unit volume is increased by 3 times in the second prototype unit making the unit more compact and efficient. Figure 6.6 shows the profiles of the plate-fins used for heat exchangers of the first and second prototype units.

Table 6.1: Comparison of plate-fin profile

Prototype unit	First	Second
Material	26 gauge GI	24 gauge Al
Thermal conductivity (kcal/kg^{o}C)	58.0	170.0
Plate thickness (m)	1×10^{-3}	1×10^{-3}
Plate spacing (m)	17.5×10^{-3}	12.7×10^{-3}
Hydraulic radius of flow passage (m)	8.75×10^{-3}	3.0×10^{-3}
Fin length (m)	8.75×10^{-3}	6.35×10^{-3}
Fin area/total area	0.683	0.500
Total heat transfer area per unit volume (m^2/m^3)	114.28	300.00

Three passes are provided on the gas side, which enables the extraction of the heat from the gas to the maximum extent possible, resulting in improved thermal performance. Figure 6.7 shows the heat exchanger with baffle arrangement on the gas side to force the gases to flow in three passes before leaving the heat exchanger. The gas side header portion of heat exchanger is



First proto-type unit

Second proto-type unit

Particulars	First unit	Second unit
Fin pitch	75 0	25.0
Plate spacing	17.5	12 5
Hydraulic radius	8.75	3 00
Fin length	8.75	6.35
Fin area/total area	0.683	0 500
Heat transfer area (per unit volume)	114 28	300 00

(All dimensions are in mm)

Fig. 6.6 Comparison of plate-fin profiles

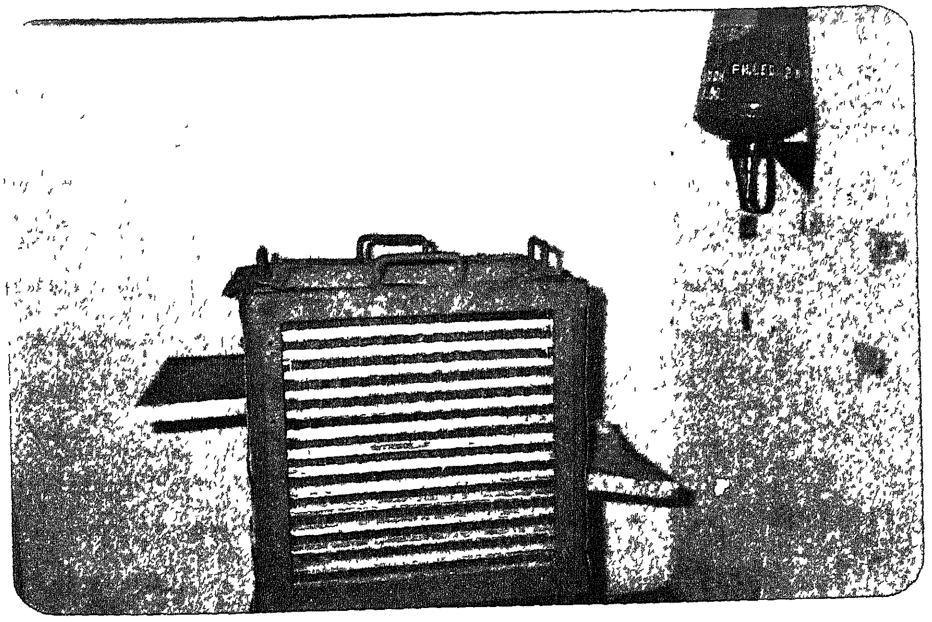


Fig. 6.7 View of heat exchanger showing baffles provided for three passes on gas side

shown in Fig. 6.8. Use of aluminium as plate fin material also improves thermal performance due to higher thermal conductivity. Aluminium also makes the fabrication of plate fins easy. All the plate-fins are assembled in the angle iron box to make the unit compact and easy to handle. Figure 6.9 shows the process of assembling plate-fins and plain sheets in the heat exchanger. The detailed technical drawing of modified heat exchanger is given in Fig. 6.10. From the prediction of performance based on the methodology given in chapter 4 it is seen that the hot air available from this heat exchanger is sufficient to dry approximately 200 kg of fresh cardamom.

6.2 Fabrication of the Plate-fins for Heat Exchanger

The main objective in designing the drying system is to make it more efficient but at the same time the system should be easy to fabricate. Since the system is going to be used in remote hilly areas the emphasis was on a fabrication method which can be carried out at workshops in nearby small towns. Fabrication of furnace and cabinet tray dryer is relatively simple and can be carried out in a small workshop without much difficulty. Fabrication of the plate-fin of the heat exchanger is tricky and unfamiliar to the workshops in remote areas.

To fabricate the plate-fin easily without using any mould or press, a simple bending device is developed as shown in Fig. 6.11. Firstly aluminium sheet is cut as per the required size. Then it is kept on the two square rods fixed apart on the bending device. Then the square slot is made by hitting another square rod from the top. Then the first slot is held in position with

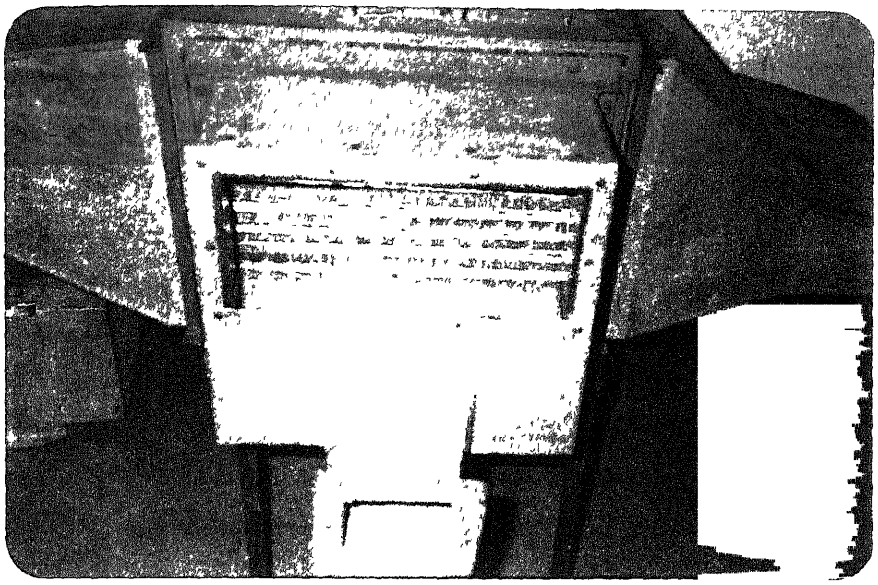


Fig. 6.8 Gas side header of heat exchanger

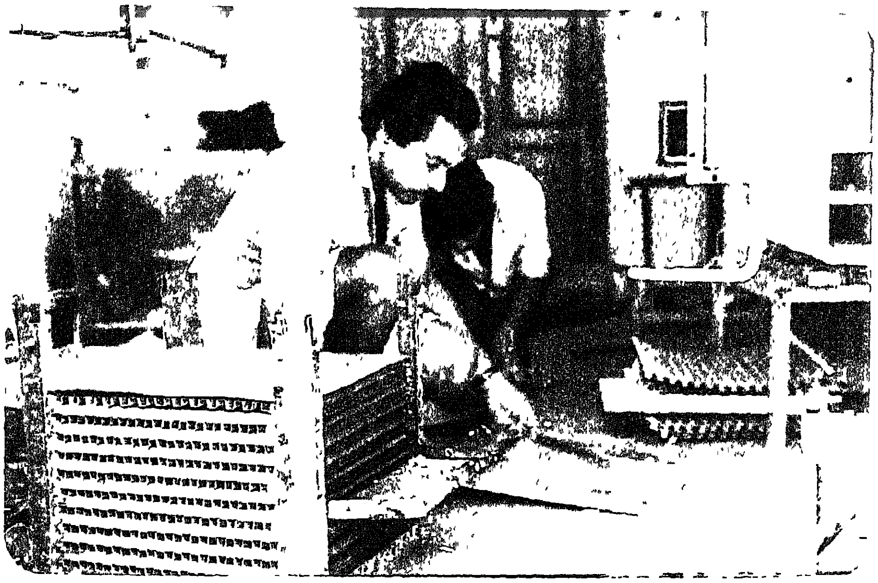


Fig. 6.9 Assembling of plate-fins of heat exchanger

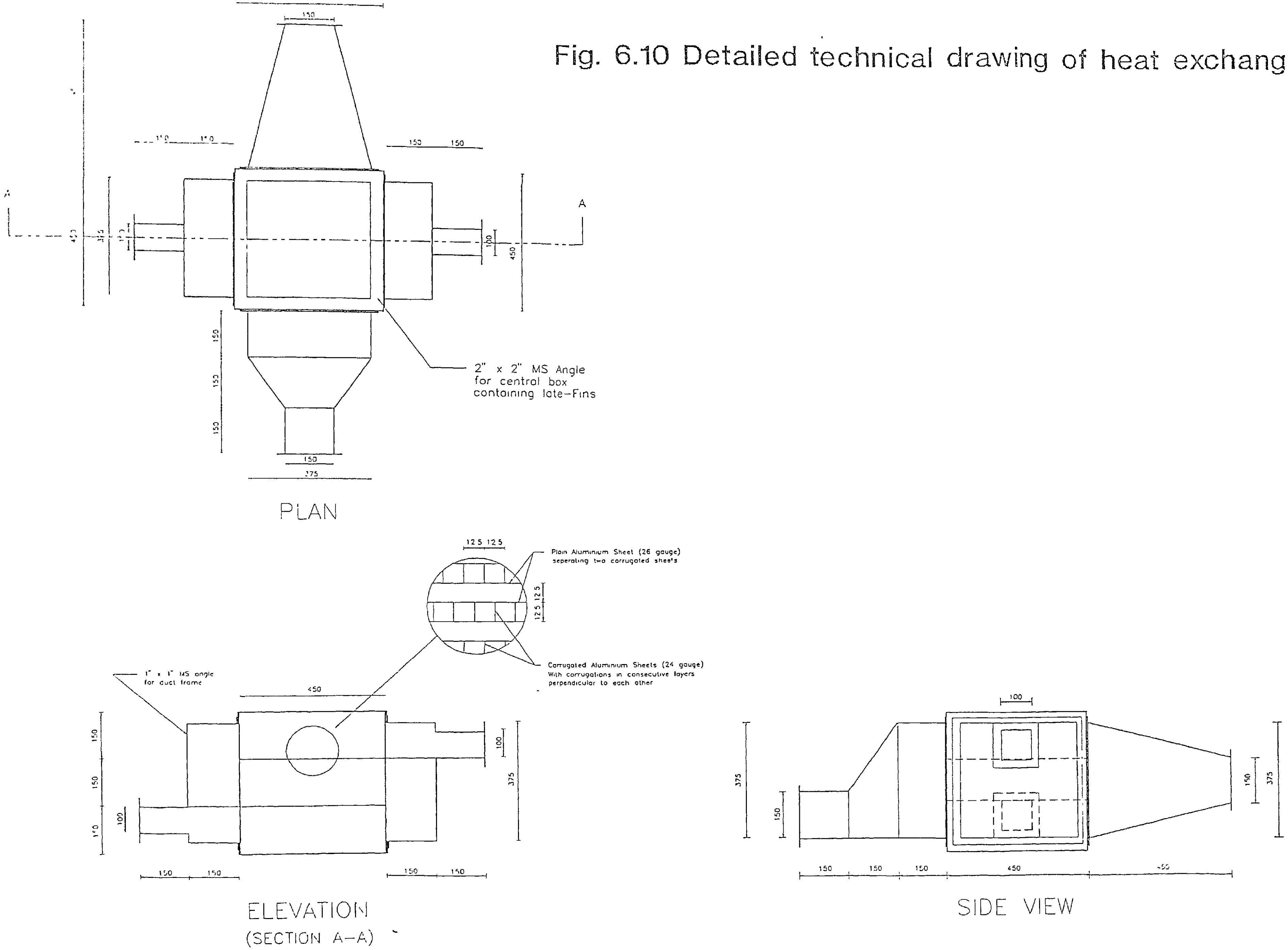

PLAN
2" x 2" MS Angle for central box containing late-Fins
A
A
450
150
150
150
150
375
100
450
ELEVATION
(SECTION A-A)
1" x 1" MS angle for duct frame
Plain Aluminium Sheet (26 gauge) seperating two corrugated sheets
Corrugated Aluminium Sheets (24 gauge) With corrugations in consecutive layers perpendicular to each other
12.5 12.5
450
375
100
SIDE VIEW
100
375
150
450

Fig. 6.10 Detailed technical drawing of heat exchanger

square rod lever and C-clamps and successive square corrugations are made as shown in the Fig. 6.12. To ensure parallel movement of sheet, a guide channel is provided as shown in Fig. 6.13. With the help of this two plate-fins can be fabricated per hour easily with the help of hammer and C-clamp only. Photograph in Fig. 6.14 shows a single person fabricating the plate-fin of heat exchanger with the help of the above mentioned simple device developed for this purpose.

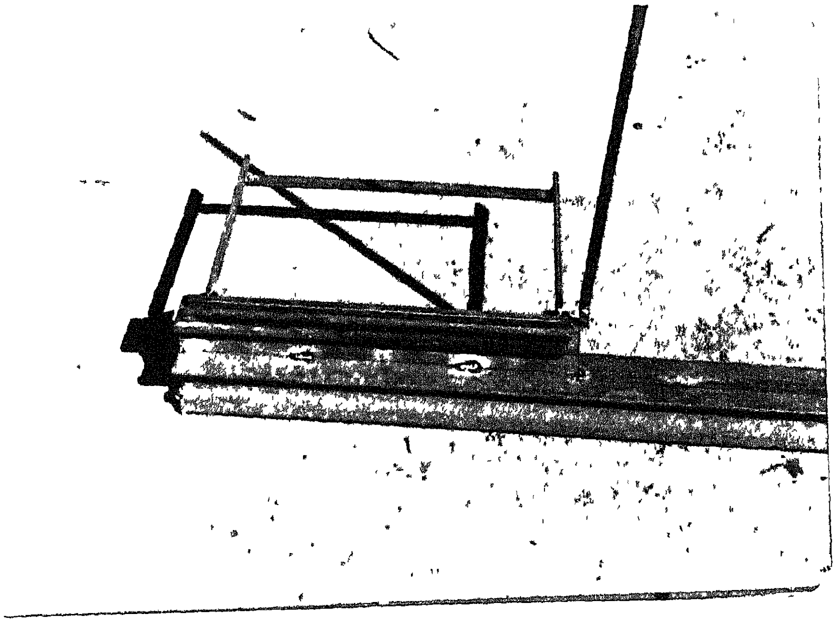


Fig. 6.11 Complete view of device for fabricating plate-fins

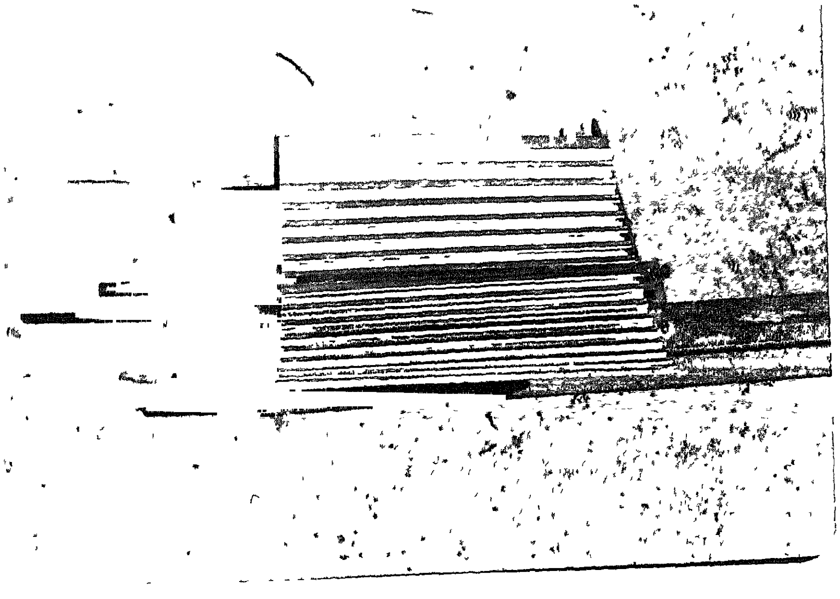


Fig. 6.12 View showing method of holding the sheet during fabrication of plate-fin

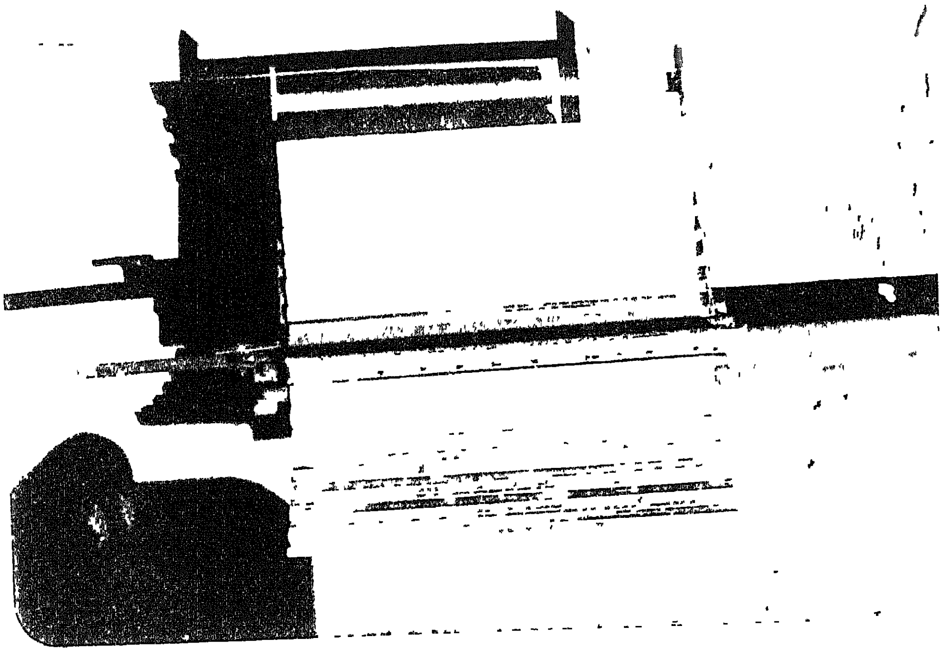


Fig. 6.13 Provision made for proper guidance of sheet during fabrication of plate-fin

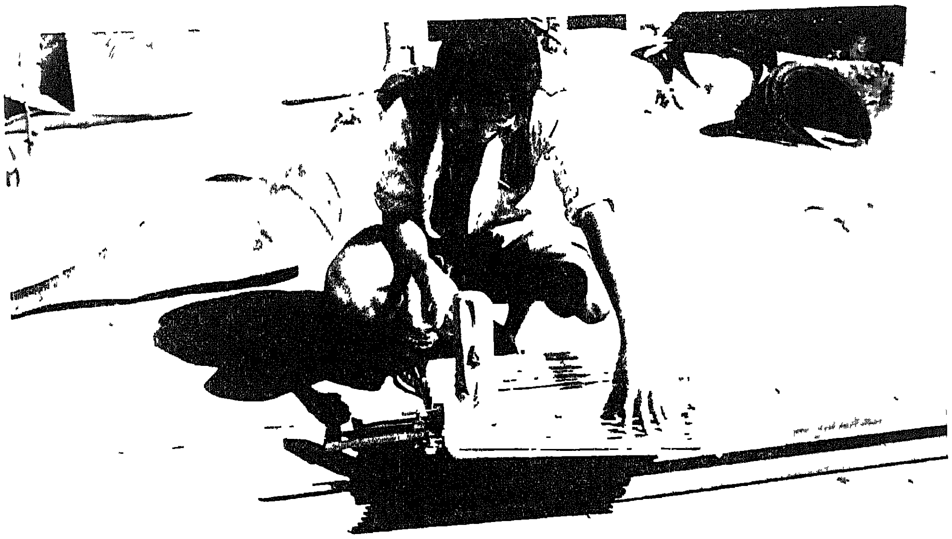


Fig. 6.14 Fabrication of a plate-fin with the developed device by a single person

7. FIELD TESTING OF THE SECOND PROTOTYPE UNIT

7.1 Some Problems Faced During Field Testing

During our survey tour to many estates in south India during October-December 1989 we collected information about the existing drying methods used in the fields. Another objective of that survey was to establish contacts with the field personnel and to choose a few sites for possible field testing of the prototype drying unit for a few cash crops. During the survey we identified 2-3 sites for field testing and finally decided to do it in cooperation with UPASI (United Planters Association of South India), Vandiperiyar who are also actively working on improving dryers for cardamom. Dr. V. Govindarajulu (Senior Scientific Adviser of UPASI) assured us full cooperation in the field testing. So it was decided to test the unit in one of the estate in the Vandiperiyar region. The other consideration in selecting that site is the availability of cash crops like cardamom, pepper, coffee at the same place. Vandiperiyar is located in Idduki district of Kerala at about 800 m. above sea level and about 100 km. from Kottayam where cardamom production is a major activity. Also there are many tea factories around Vandiperiyar where diesel generators are available to ensure 24 hours electricity supply.

The major components of the system, viz. furnace, heat exchanger and dryer were fabricated in New Delhi. All these components along with two blowers and necessary equipments such as weighting balance, temperature indicators, flow meters, variac etc. were transported to Kerala by road transport. During transport the heat exchanger and furnace got damaged. The inlet and outlet gas header portion of the heat exchanger, primary air inlet opening mechanism of furnace and fire brick lining of the furnace which got damaged during transport were repaired at Vandiperiyar with the help of local fabricators.

With the help of contacts of Dr. V. Govindarajulu it was decided to install the unit near a cardamom store in the Dymock estate of M/s. Harrison Malayalam Limited. This cardamom store is located approximately 7-8 kms from UPASI campus. The complete drying unit, consisting of blowers, furnace, heat exchanger and cabinet tray dryer, was installed in the premises of the cardamom store with the help of local fabricators and labourers from tea factory and cardamom store of the estate.

The major difficulties faced during the field testing of the unit were food, conveyance and accommodation. UPASI provided one of their vacant staff quarter for accommodation and provided maximum possible help during the stay there. In order to solve the problem of food, decision was taken to furnish the house with minimum necessary things and start operating the kitchen also.

Since the area is hilly, the common local mode of transport is jeep-taxi. But since the experiment used to take upto 15 hours, conditions forced us to use cycles, tractors for conveyance to the extent that some times walking in the dark forest in midnight became unavoidable.

Scarcity of hardware shops was another major constraint during field testing. Even for nut-bolts and rivets, it became necessary to bring them from Cumbum town situated in Tamil Nadu, approximately 20-25 km away from the site.

Though we planned to start the experiments in October 1990, due to problems faced during transport of the material to Kerala the material reached Vandiperiyar only in October end. Due to various problems faced as mentioned above viz. language, scarcity of hardware items, fabricator, etc. assembling of the unit took more time than expected and the unit became operational only during last week of November.

During field testing of the unit, experiments were conducted for drying of cardamom, pepper and coffee. Since the unit became operational by November end the good quality crop of cardamom could not be tried in the unit due to its unavailability. The performance will be better if the fresh capsules are fully matured.

Though the quantity of the hot air available with the furnace heat exchanger combination is sufficient to dry approximately 200 kg of cardamom, only a small wooden cabinet tray dryer was used to test the viability of the system. The idea was to see the feasibility of drying the capsules faster resulting in reduced drying time by utilizing forced flow methods on air side.

Another point which should be noted here is that Leco (coal) which was utilised during field testing was not of the best quality due to an acute shortage during that period. Approximately 20-30% of the powdered form of leco used to pass unutilised through the grate.

7.2 Assembling of the Prototype Unit

All the components of the system (furnace, heat exchanger, cabinet tray dryer, blowers, etc.) and other necessary items such as tool kit, insulating material, and various instruments to measure temperature, flow, weight etc. were transported to the site via Kottayam. After reaching there the actual site was selected for installation of the second prototype unit with the help of UPASI. The main consideration was availability of power and fresh sample of cash crop. The unit was assembled in the premises of a cardamom store at Dymock with the help of a local fabricator and estate personnel. Photographs shown in Fig. 7.1, 7.2 and 7.3 show the overall view of the complete assembled unit from different angles showing various components.

Initially the hot flue gases were passed in the lower portion of the heat exchanger as the first pass. This needed an additional duct connecting the furnace outlet to heat-exchanger inlet. After one trial the arrangement was changed and the furnace outlet was connected to top portion of the heat exchanger. This reduced the duct length containing high temperature flue gases resulting in reduction of heat losses. Also, since now the top surface of the heat exchanger is hot it became easy to insulate it just by putting ceramic fiber insulation sheets making perfect contact with the top surface.

During the first few trial runs it was observed that unlike with charcoal, it was not possible to maintain continuous burning of leco coal on natural draft mode. So a small induced draft blower was installed to suck the flue gases through the heat

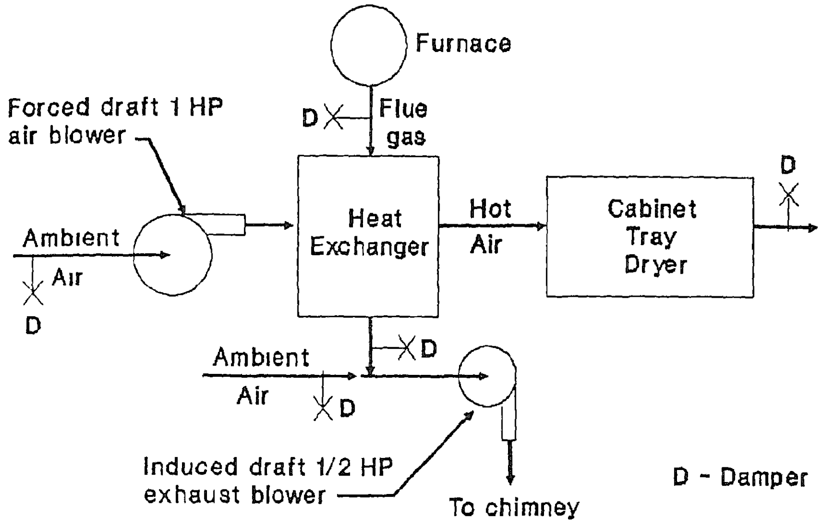


Fig. 7.4 Schematic diagram of the complete system

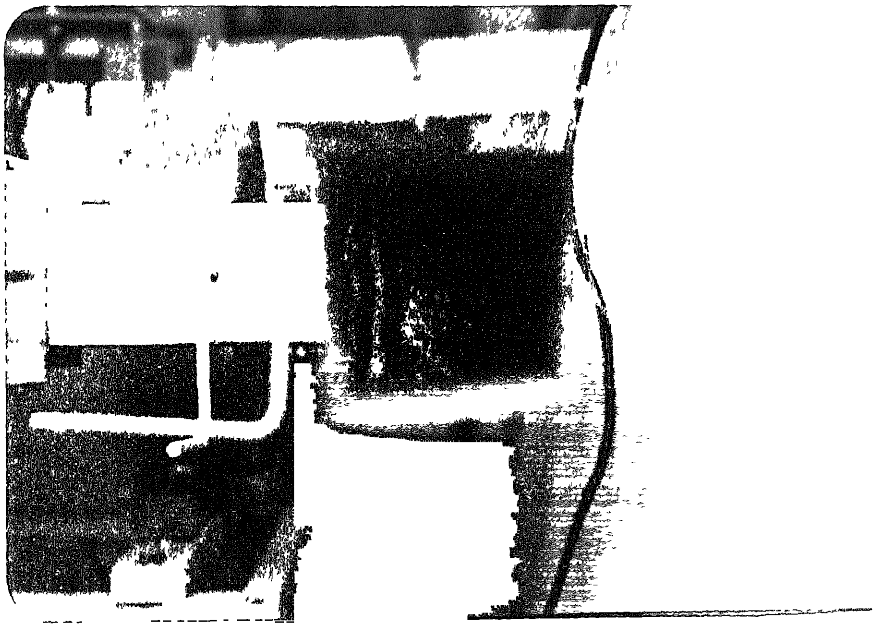


Fig. 7.5 Close up of the system showing damper for adjusting draft

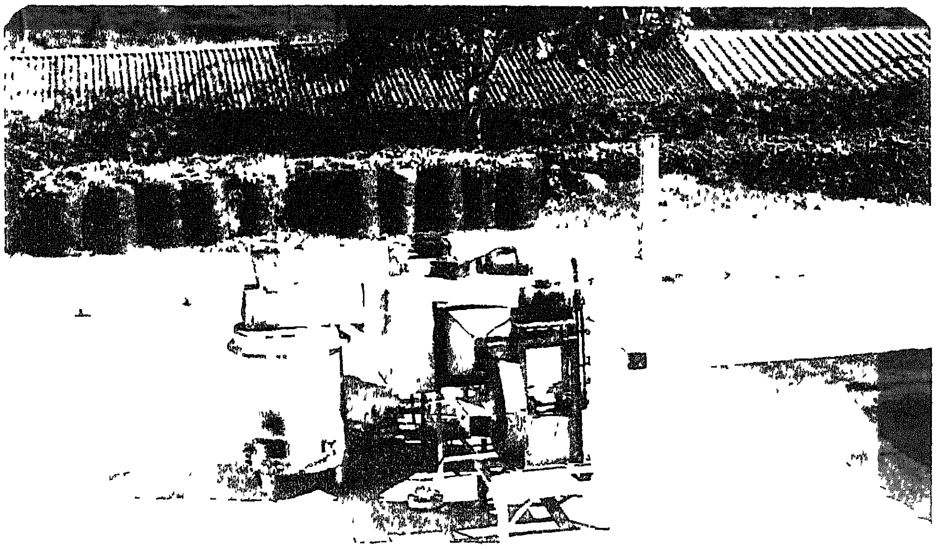


Fig. 7.3 Side view of the complete system

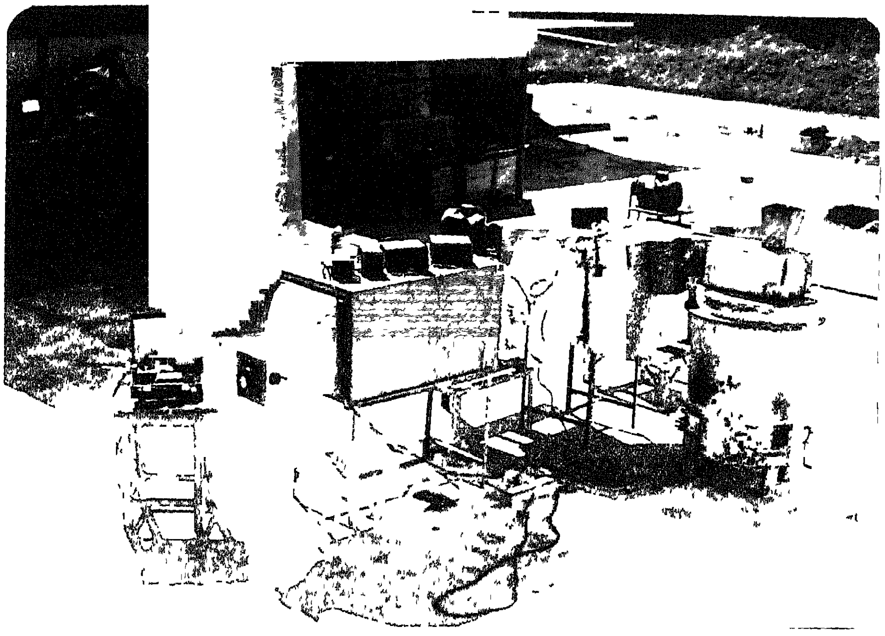


Fig. 7.1 Overall view of the system from furnace side

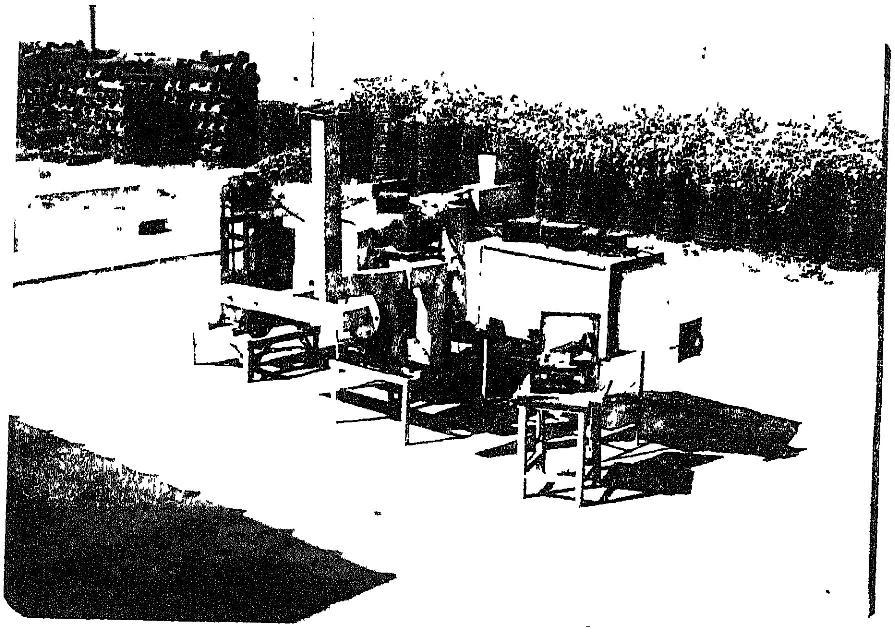


Fig. 7.2 Overall view of the system from front side

exchanger and throw them out to the atmosphere through a chimney. For this purpose one bypass duct was also attached to the duct connecting the flue gas outlet of heat exchanger and the exhaust blower inlet. Dampers are provided in both air and gas ducts to control air and gas flow rates to the exhaust blower. The schematic diagram of the complete arrangement is given in Fig. 7.4. Figure 7.5 shows a close up of the arrangement. Adjustment of these two dampers helps in controlling the draft available to the furnace, thus helping in controlling the burning rate.

Another advantage of this arrangement is that the exhaust gas is mixed with atmospheric air after heat exchanger before entering into the exhaust blower, thereby avoiding heating of the blower. Both air and flue gas exhaust blowers used are belt driven type blowers, which enables one in changing the speed (rpm) of impeller to vary the air flow range in large steps with fine tuning provided by the dampers installed in the ducts. Using a belt driven blower for exhaust also helps in keeping the motor away from the hot impeller, thus isolating it from heat.

7.3 Instrumentation

In order to evaluate the performance of the system, different parameters were monitored throughout the experiment, as listed below:

(i) Fuel consumption rate

(ii) Temperature, flow rate, relative humidity of the air

(iii) Temperature at various points in the three passes of flue gas through heat exchanger

(iv) Ambient temperature

(v) Rate of moisture loss from the product and moisture content.

For measurement of temperature at different sections in the air and gas streams and inside cabinet tray dryer, K-type thermocouples were installed. Two multi-channel digital temperature indicators (Instronix India make, 1°C least count) were used to monitor variations in the temperature at different points. In addition, portable temperature indicators (one Massibus make and other Instronix India make with range 0-1000°C, 0-200°C and least count of 1°C, 0.1°C respectively) were used. In order to measure relative humidity of air multi-channel temperature indicator of Instronix India make indicating dry and wet bulb temperature (using PT-100 thermocouple probe) were installed at inlet and outlet side of the dryer. In addition to this, portable temperature and humidity indicator (Switzer make MIK 3000, range: 0-100% RH, -20 to 80°C with least count of 1% RH and 0.1°C respectively).

For measuring the burning rate the amount of leco added was monitored as a function of time. Vane type mechanical anemometer was used to measure the flow rate of air.

In order to calculate moisture content and rate of moisture loss, the weight of the product was measured after fixed intervals of time. In addition to this, 20 grams of the cardamom sample was taken out after every three hours from a few trays to get moisture contents at different times during drying. These samples were analysed in the UPASI laboratory where moisture content of the capsule is determined by the Dean and Stark apparatus.

7.4 Cardamom Drying

Drying of cardamom is a very delicate process since a close control on operating conditions is necessary to maintain its green colour (which fetches good market price) and to avoid bubbling or splitting of capsules. Fresh cardamom capsules were made available by M/s. Harrisons Malayalam and UPASI for most of the experiments. Fresh cardamom is spread on a SS wire mesh in mono-layer and placed inside the cabinet tray dryer. Hot air from the heat exchanger is passed parallel to trays. In all, a total sixteen trial runs were conducted on cardamom drying. Every time approximately 500 grams of fresh cardamom capsules were spread on each tray is approximately 5 kg of fresh cardamom capsules are dried in each trial run. During initial runs, stress was on seeing whether green colour is maintained under fast drying using forced flow of hot air. After achieving this satisfactorily 20 gram samples from one or two trays is taken out and analysed in UPASI laboratory to measure its moisture content at different times during the drying process. For determining the moisture content of cardamom the Dean and Stark apparatus is used. Also, weight of the cardamom in different trays is monitored at regular intervals to evaluate loss of moisture and moisture content at different times during the drying process. Cardamom is loaded inside the drying chamber which has an initial temperature of about 38-40^{o}C. The air temperature is then gradually increased to 55°C within 5-6 hours and then maintained between 55-58°C till the drying is completed. It was observed that it is possible to dry cardamom within 14-15 hours. The graphs in Figs. 7.6 to 7.17 show the variation of weight loss, moisture content (wet basis and dry basis) with drying time for three sample runs of the drying unit for drying cardamom. These graphs shows variation in different parts of the dryer such as top, bottom, left, right etc. and also for complete dryer.

7.5 Estimation of Cardamom Moisture Content

For estimation of cardamom moisture content a 20 gram sample was taken out from a particular tray at regular interval of 3 hours and later analysed in UPASI laboratory using Dean and Stark apparatus. The Dean and Stark apparatus consists of a round flask fitted with a condenser and graduated collecting apparatus. An electric heating mantle with a thermostat is used for heating the flask and the contents. The description of the method is as follows:

Twenty grams of sample cardamom capsules are boiled (80°C) in laboratory grade in Toluene in a round bottom flask for about 3 hours. The moisture extracted from the capsules is condensed and collected in the receiver. Water being heavier than Toluene is collected at the bottom of the apparatus. The volume of water thus collected (in ml) is converted into percentage of moisture in the cardamom capsules (i.e. if 1 ml of water is obtained from 20 g of capsules, the moisture content of the capsules is 5%).

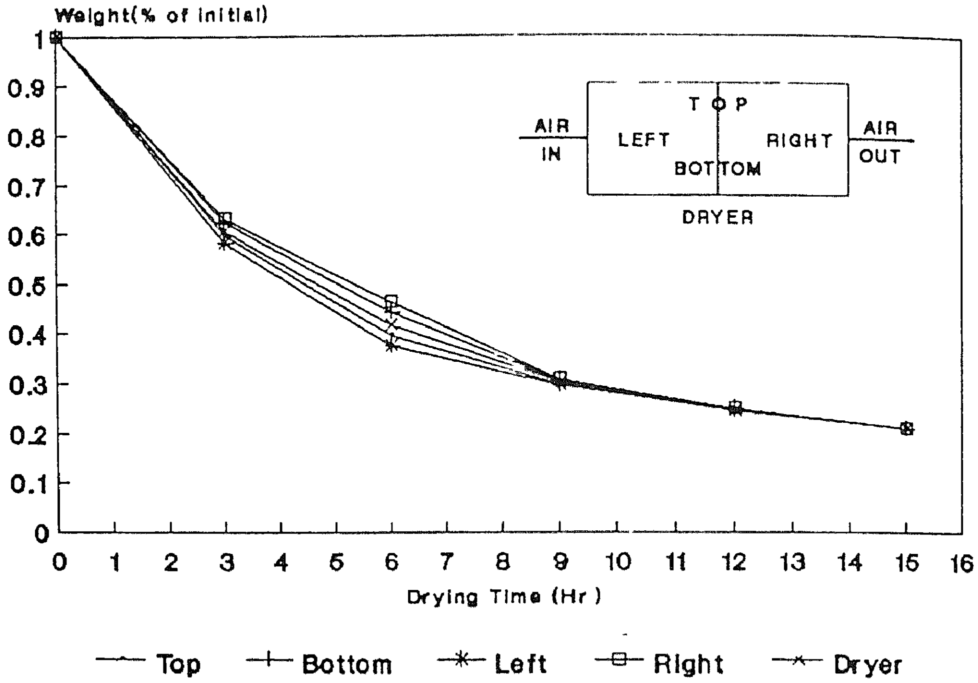


Fig. 7.6 Cardamom drying: weight loss curve
(Date:- Dec. 21-22, 1990)

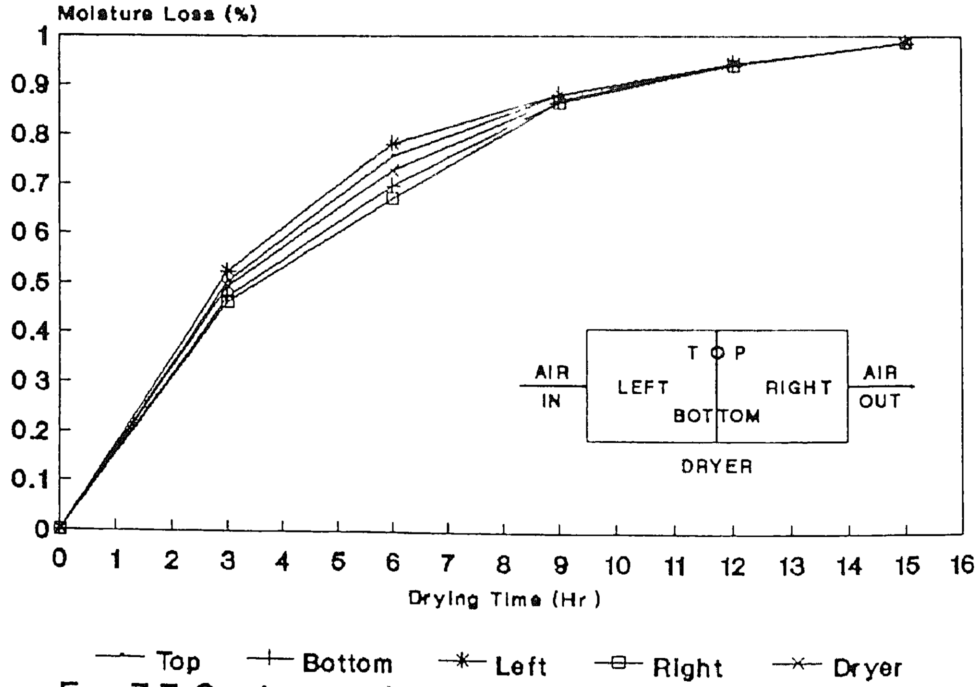


Fig. 7.7 Cardamom drying: moisture loss curve
(Date:- Dec. 21-22, 1990)

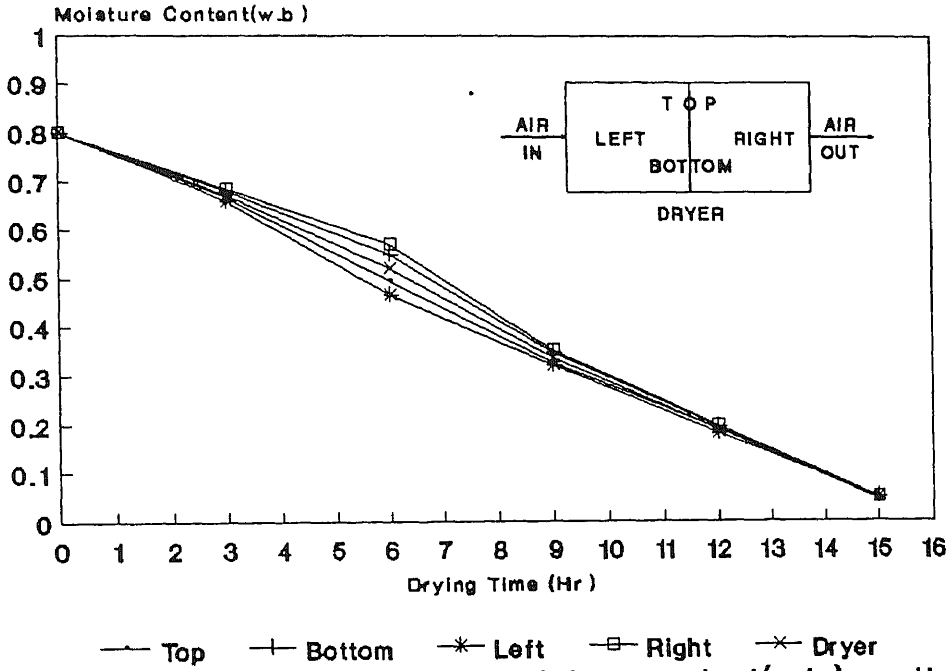


Fig. 7.8 Cardamom drying: moisture content(w.b.) vs. time
(Date:- Dec. 21-22, 1990)

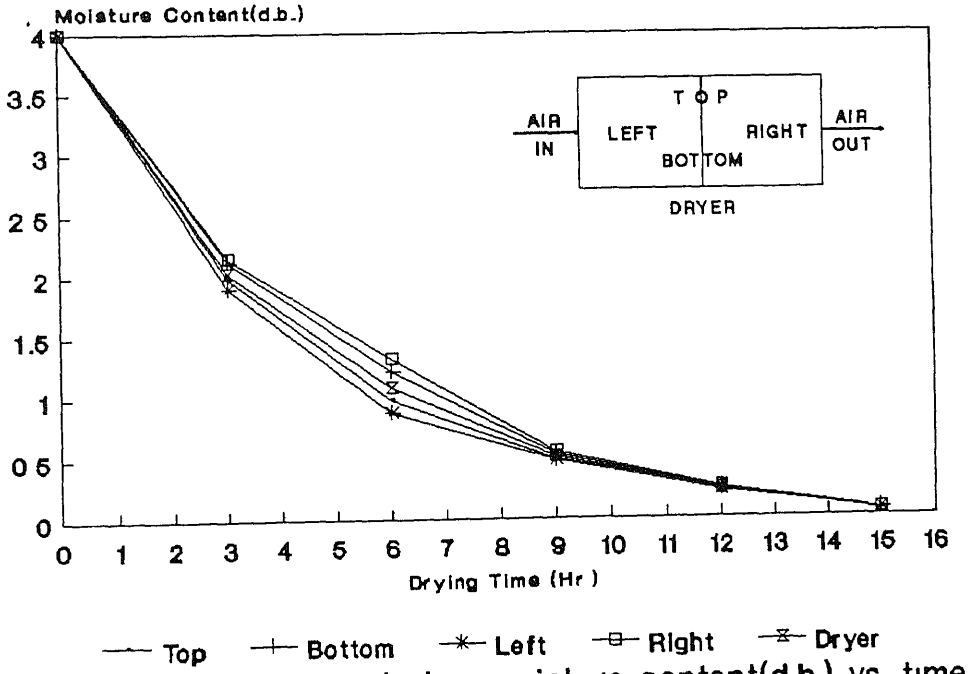


Fig. 7.9 Cardamom drying: moisture content(d.b.) vs. time
(Date - Dec. 21-22, 1990)

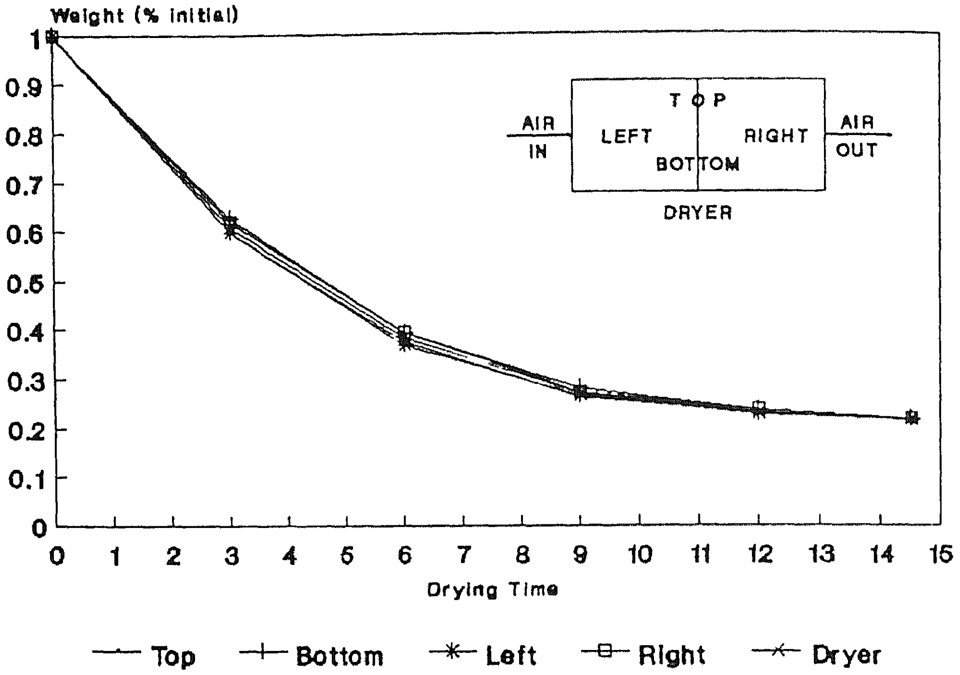


Fig. 7.10 Cardamom drying: weight loss curve
(Date:- Dec. 22-23, 1990)

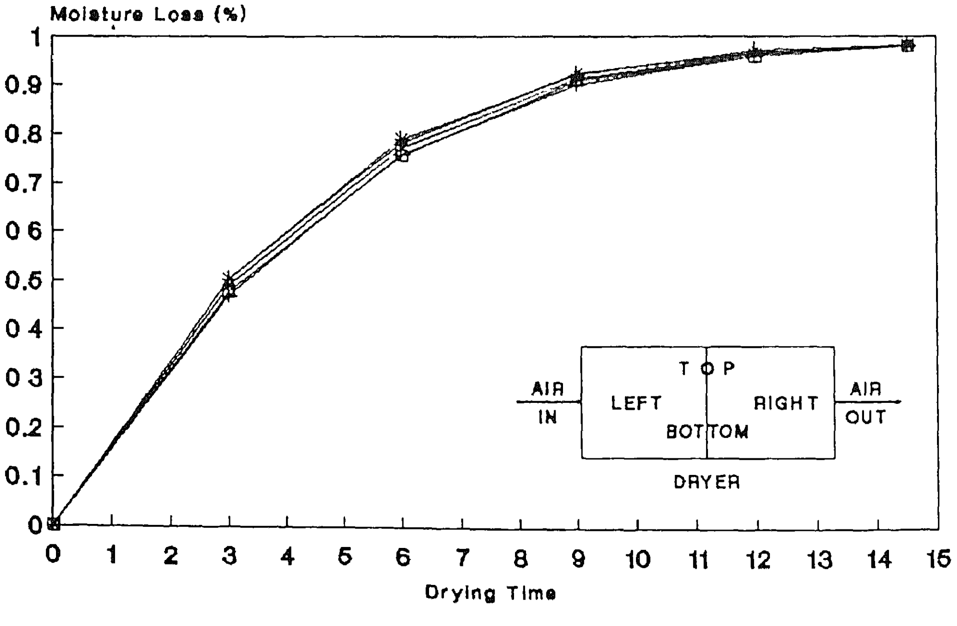


Fig. 7.11 Cardamom drying: moisture loss curve
(Date.- Dec 22-23, 1990)

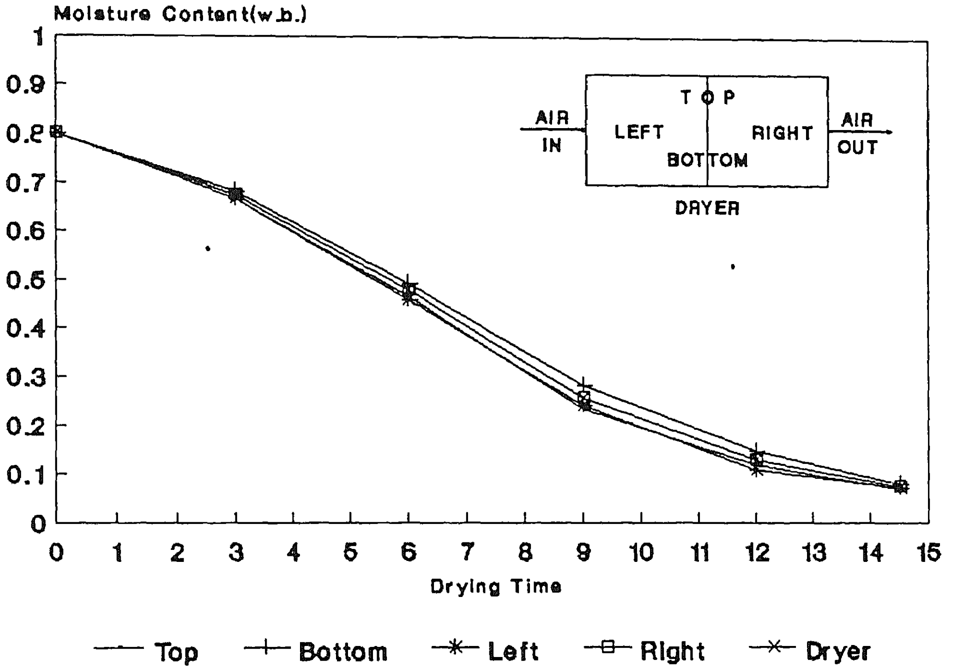


Fig. 7.12 Cardamom drying: moisture content(w.b.) vs. time
(Date:- Dec. 22-23, 1990)

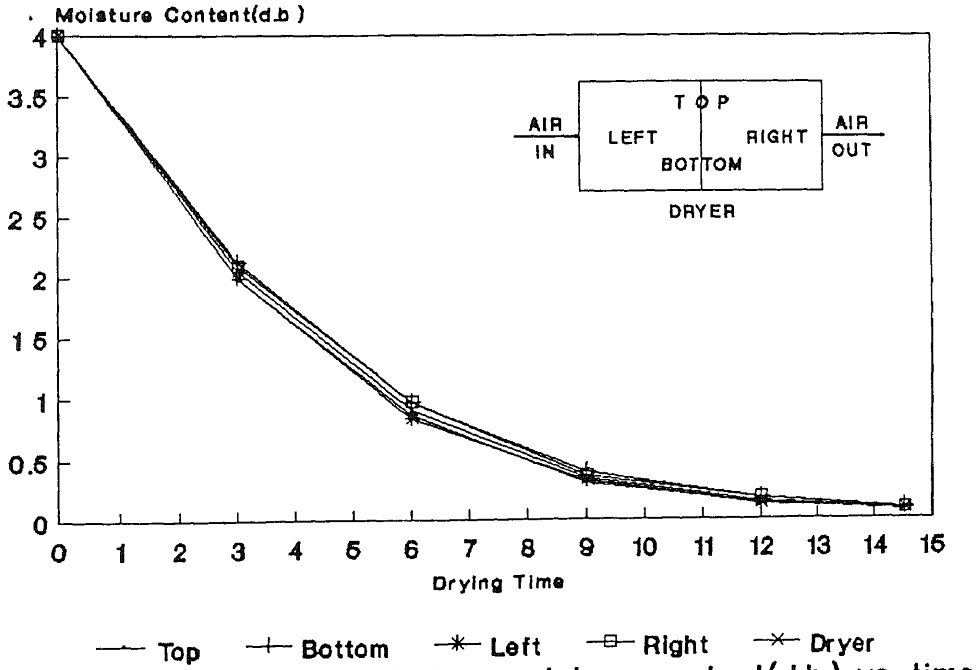


Fig. 7.13 Cardamom drying: moisture content(d.b.) vs. time
(Date.- Dec. 22-23, 1990)

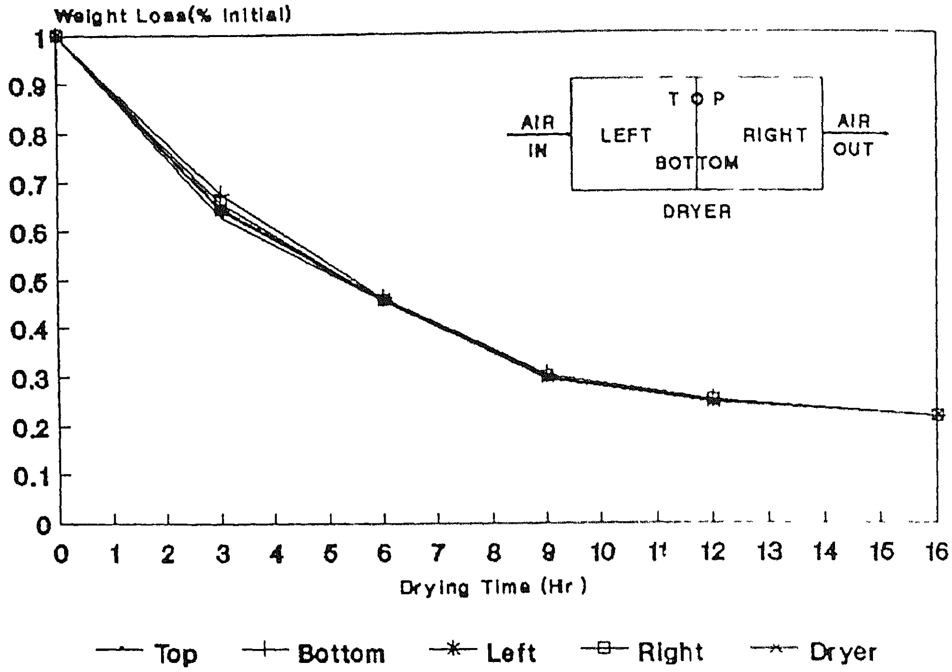


Fig. 7.14 Cardamom drying: weight loss curve
(Date:- Dec. 23-24, 1990)

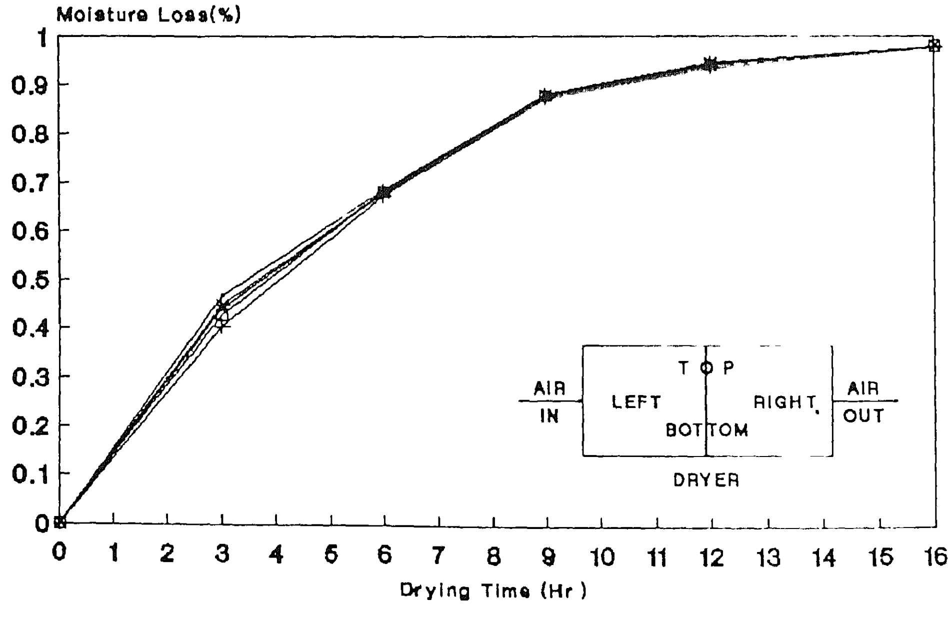


Fig. 7.15 Cardamom drying: moisture loss curve
(Date - Dec. 23-24, 1990)

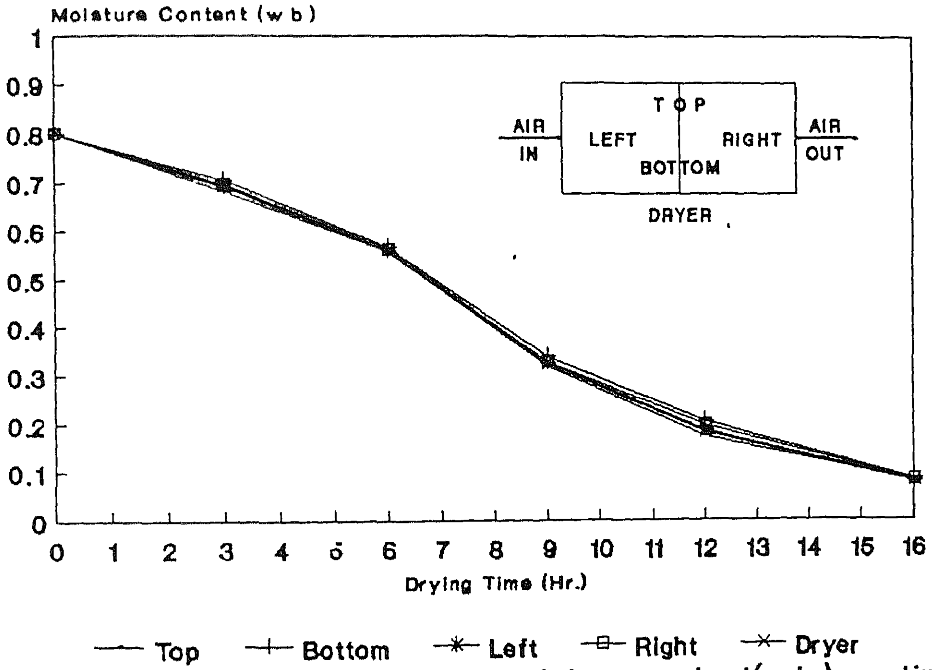


Fig. 7.16 Cardamom drying: moisture content(w.b.) vs. time
(Date:- Dec. 23-24, 1990)

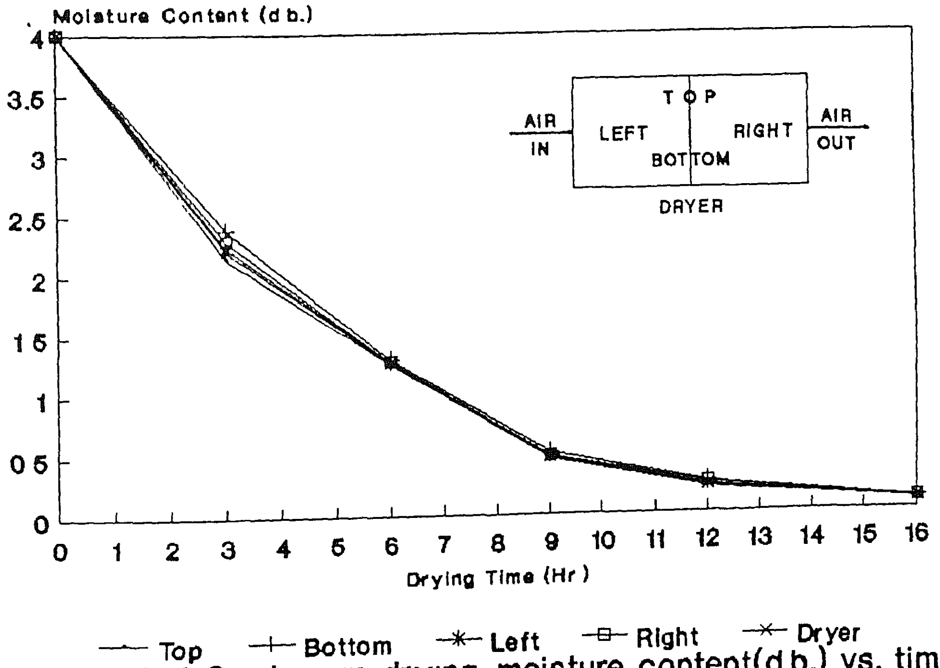


Fig. 7.17 Cardamom drying: moisture content(d.b.) vs. time
(Date.- Dec. 23-24, 1990)

Figure 7.18 shows the Dean and Stark apparatus used for estimating moisture content in cardamom. Variation of moisture content with time for a few test runs from the above method is given in Figs. 7.19 to 7.21.

From the field testing of the second prototype unit for cardamom drying it can be observed that the drying time is reduced to 14-15 hours. Using forced flow method for drying acceptable good green colour and without excessive splitting of the capsules.

7.6 Pepper Drying

As mentioned in the previous chapters currently pepper is sun dried in open yards. But as observed during field testing period, during cloudy and rainy days large quantities of pepper gets accumulated and are dried in cardamom curing chambers taking 15-18 hours for drying. The same prototype was used for drying pepper. Approximately more than ½ kg of green pepper was loaded in each tray in mono-layer. For pepper various drying temperatures ranging from 60-70^{o}C to 100-110^{o}C were tried since there is no danger of bubbling or splitting at higher temperatures which is the main constraint for faster cardamom drying. Curves showing weight loss and variations in moisture content (wet basis) at different times are shown in Figs. 7.22 to 7.27 for different drying temperatures. It is observed that pepper drying by forced flow methods using the field prototype unit can be done within 5-11 hours depending on the temperature of air inside the dryer. Thus substantial saving of time can be achieved compared to sun drying.

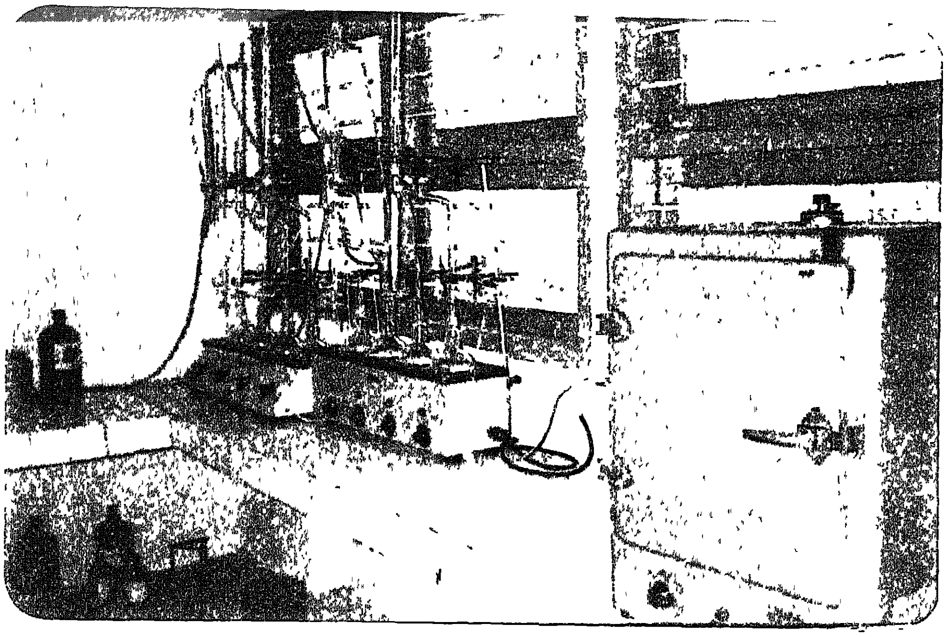


Fig. 7.18 Dean and Stark apparatus for estimating moisture content of cardamom

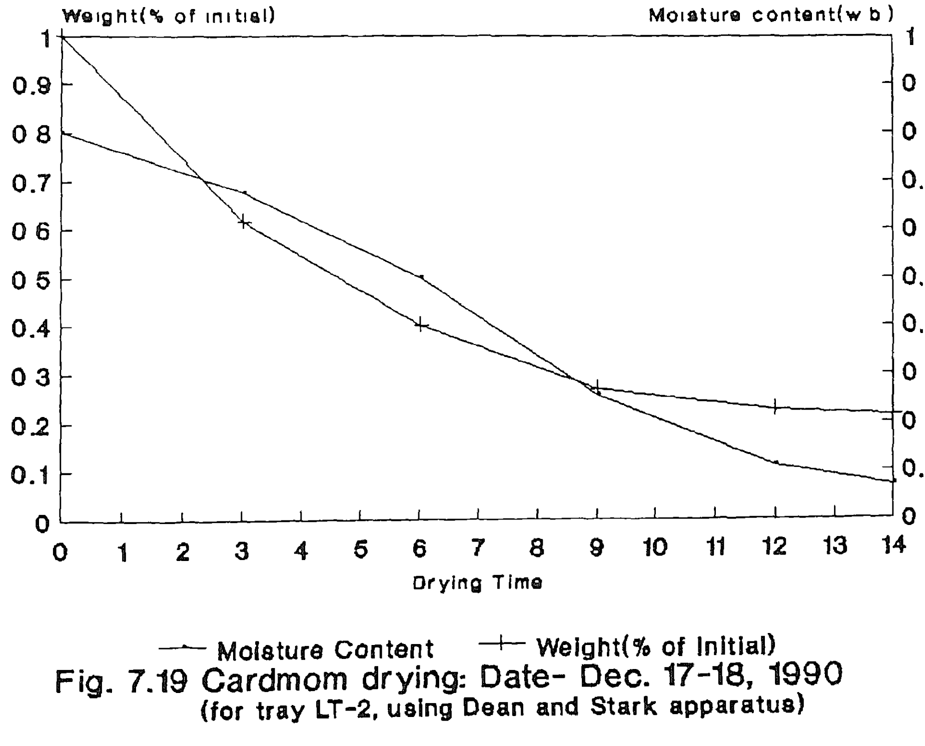


Fig. 7.19 Cardmom drying: Date- Dec. 17-18, 1990
(for tray LT-2, using Dean and Stark apparatus)

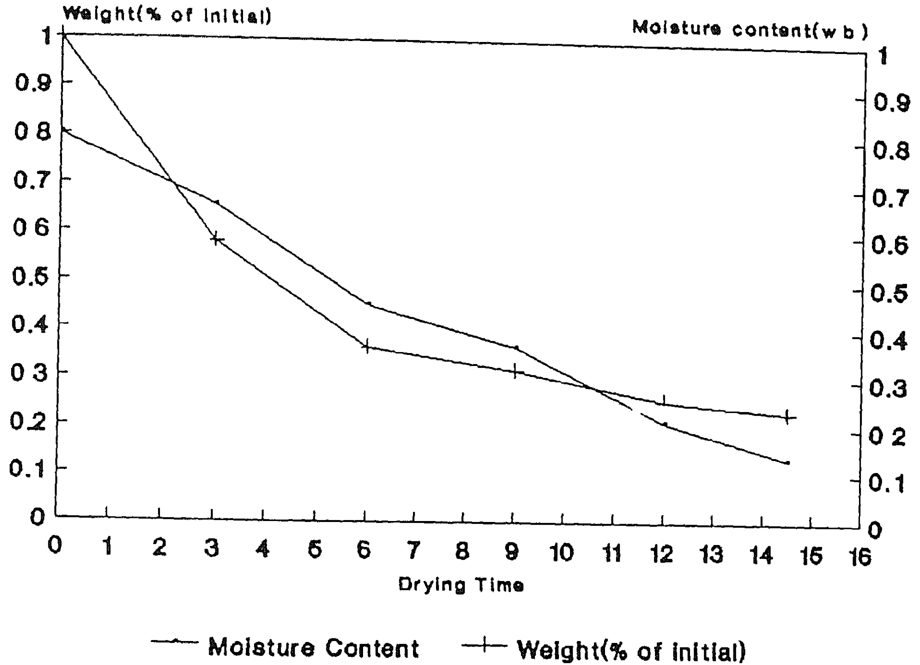


Fig. 7.20 Cardamom drying: Date-Dec. 22-23, 1990
(for tray LT-4, using Dean and Stark apparatus)

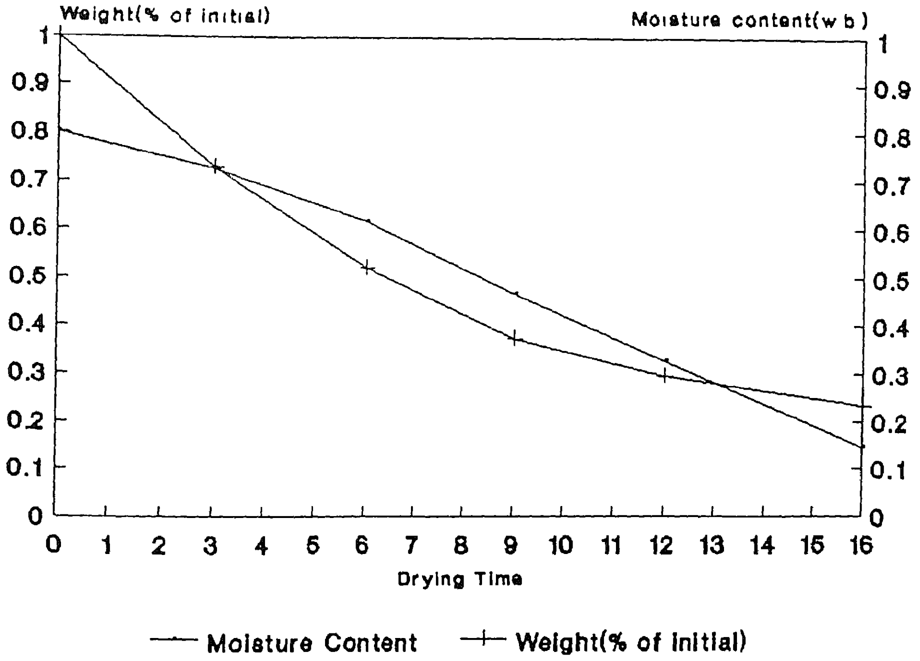


Fig. 7.21 Cardamom drying: Date- Dec. 23-24, 1990
(for tray RT-5, using Dean and Stark apparatus)

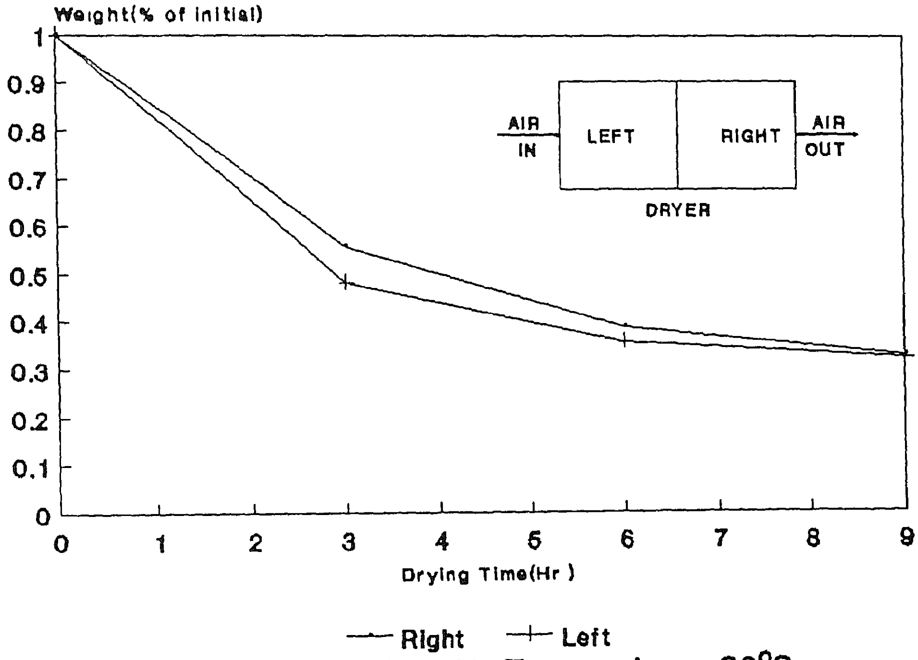


Fig. 7.22 Pepper drying: Air Temperature= 60°C
(Weight loss curve)

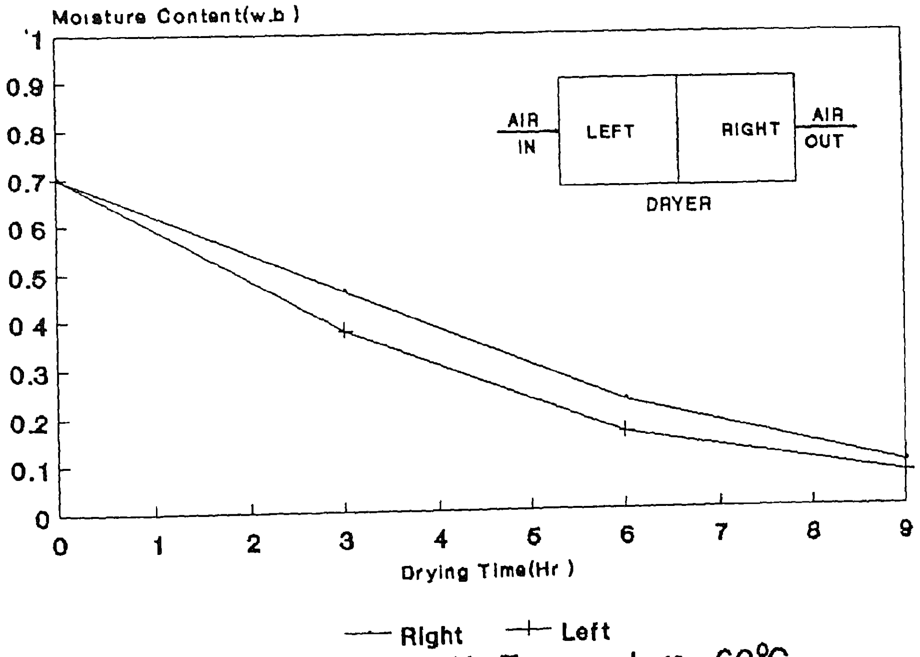


Fig. 7.23 Pepper drying: Air Temperature= 60°C
(moisture content vs. time)

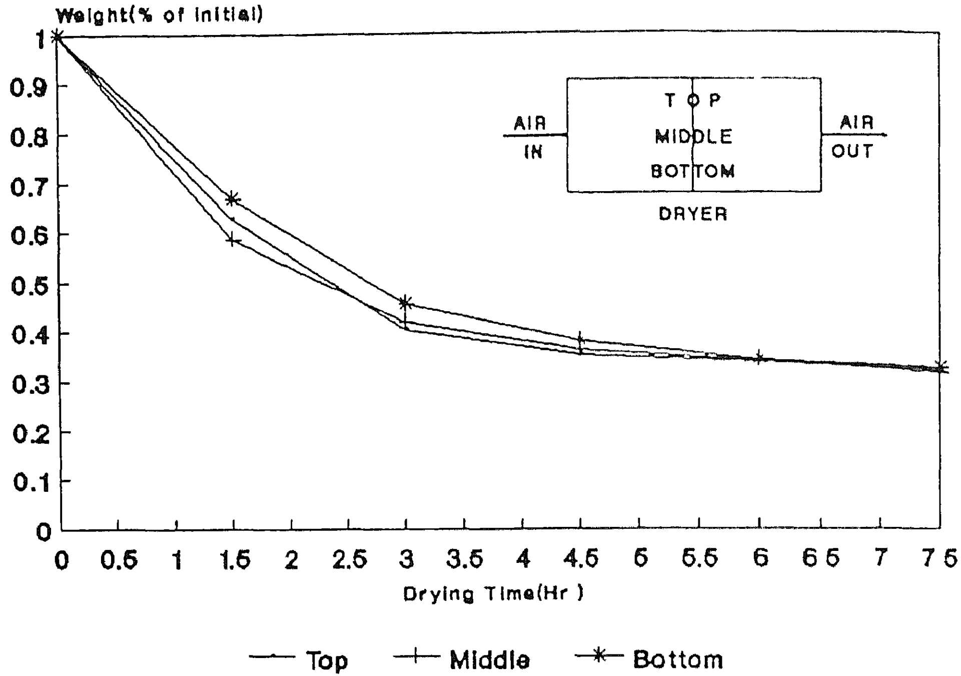


Fig. 7.24 Pepper drying: Air Temperature= 75°C
(weight loss curve)

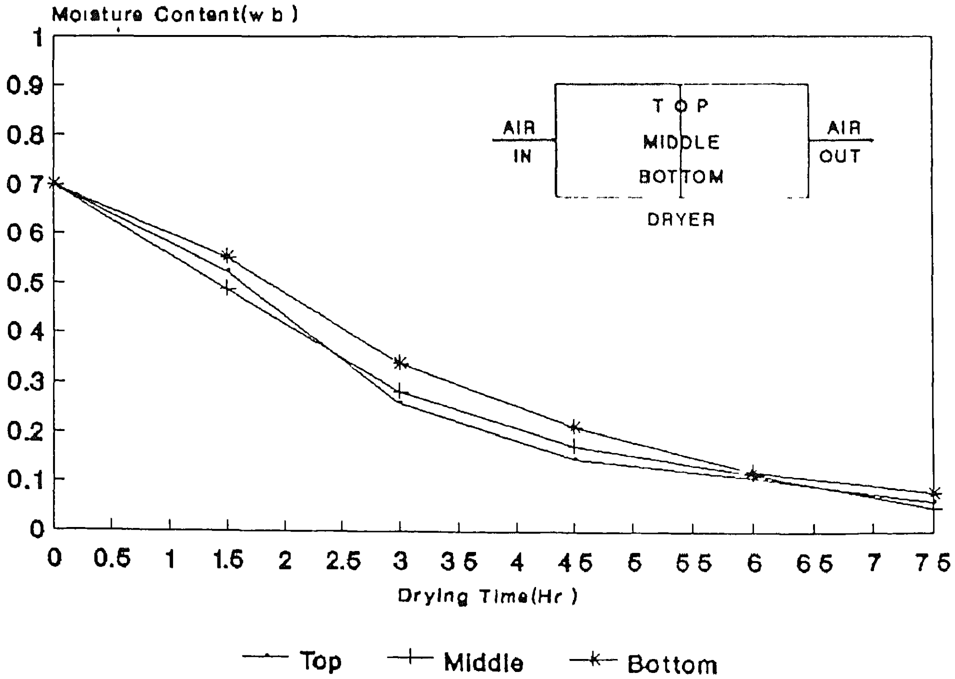


Fig. 7.25 Pepper drying: Air Temperature= 75°C
(moisture content vs time)

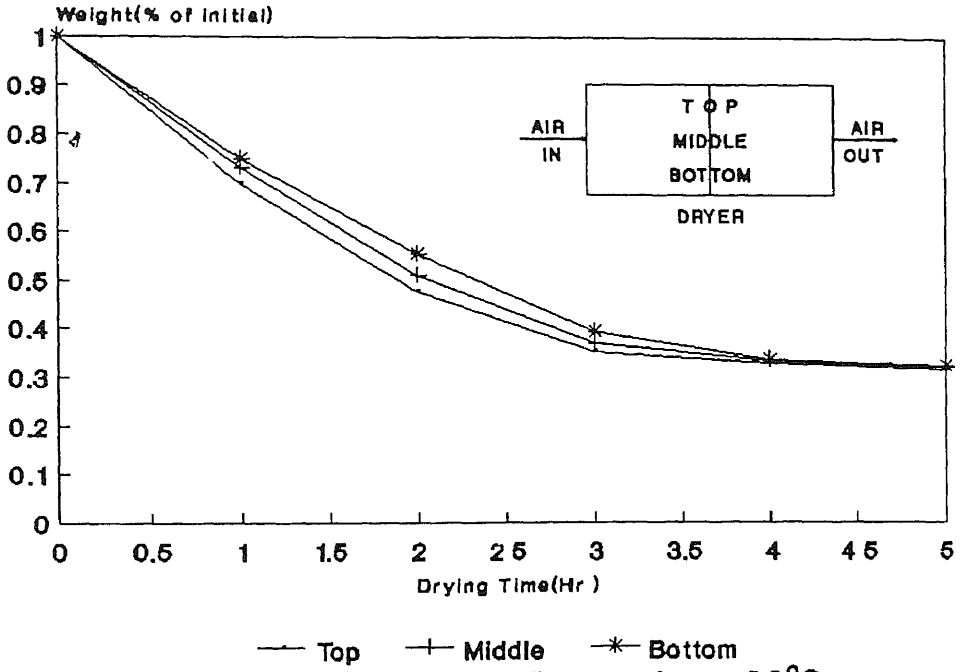


Fig. 7.26 Pepper drying: Air Temperature= 90°C
(weight loss curve)

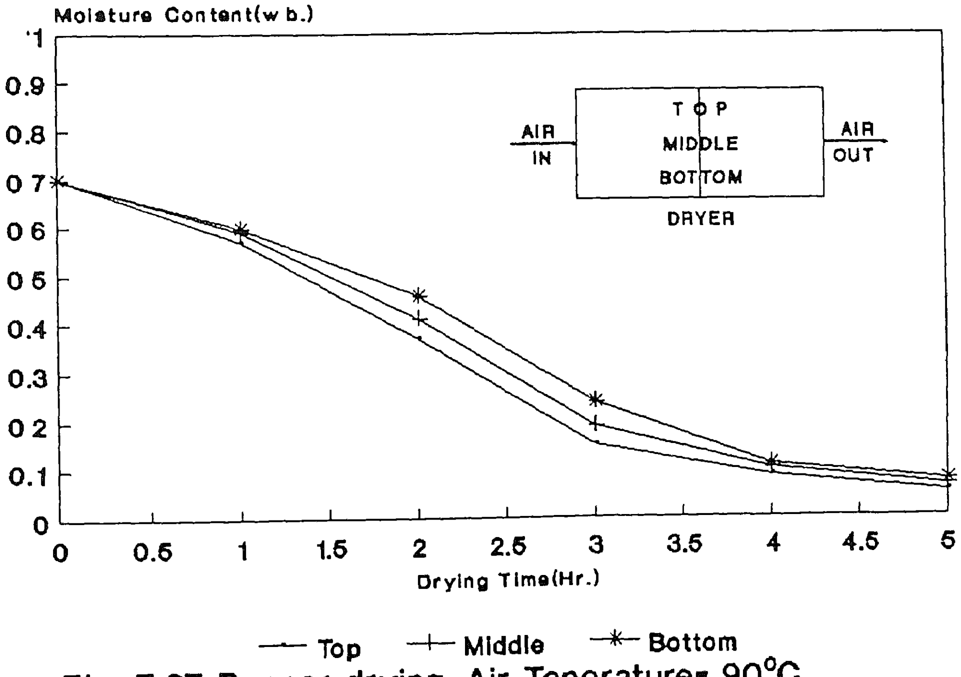


Fig. 7.27 Pepper drying: Air Teperature= 90°C
(moisture content vs. time)

7.7 Coffee Drying

At present coffee is mainly sun dried in an open cement yard partly at estate level and the rest at coffee curing houses governed by Coffee Boards. Drying of coffee under sun takes about 4-5 days. Since coffee harvesting season starts at the end of December, after drying cardamom and pepper, coffee was also dried using the prototype unit. Fresh coffee cherries are spread in mono-layer on the wire mesh tray of the dryer. Approximately ½ kg of fresh coffee cherry is spread in each tray. During trial runs it was observed that with air temperature of 80-100°C, it takes about 15 hours to reduce moisture content (w.b.) from initial value of 65-70% to final value of about 8-10%. Figures 7.28 to 7.31 shows weight loss curves and moisture content (wet basis) variation with drying time for two sets of experimental runs of the unit for coffee drying.

7.8 Thermal Analysis of The System

In order to evaluate the thermal performance of the system various parameters such as temperatures, flow rates, fuel consumption, etc. were monitored at every half an hour during drying of cash crop. From the experimental data obtained, the performance of the furnace and heat exchanger was evaluated. Experimental data was taken at a very small interval and since the burning of leco in the furnace was not at a steady state condition, the performance of the unit was evaluated taking average values for the entire drying experiment for each batch. The summary of results of the analysis for twenty experimental runs is given in Table 7.1 and gives an idea of the overall

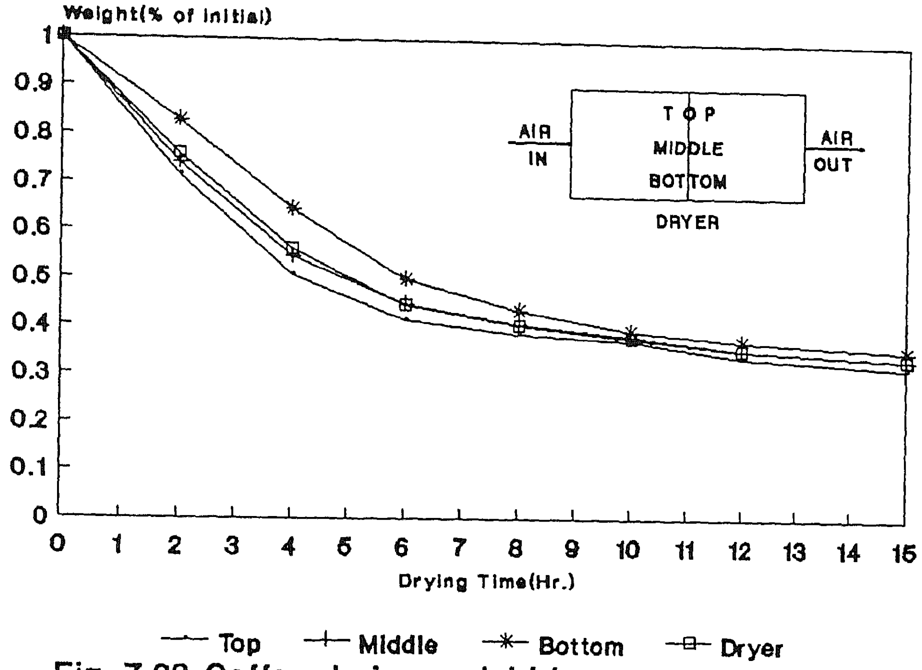


Fig. 7.28 Coffee drying: weight loss curve
(Date:- Jan. 1-2, 1991)

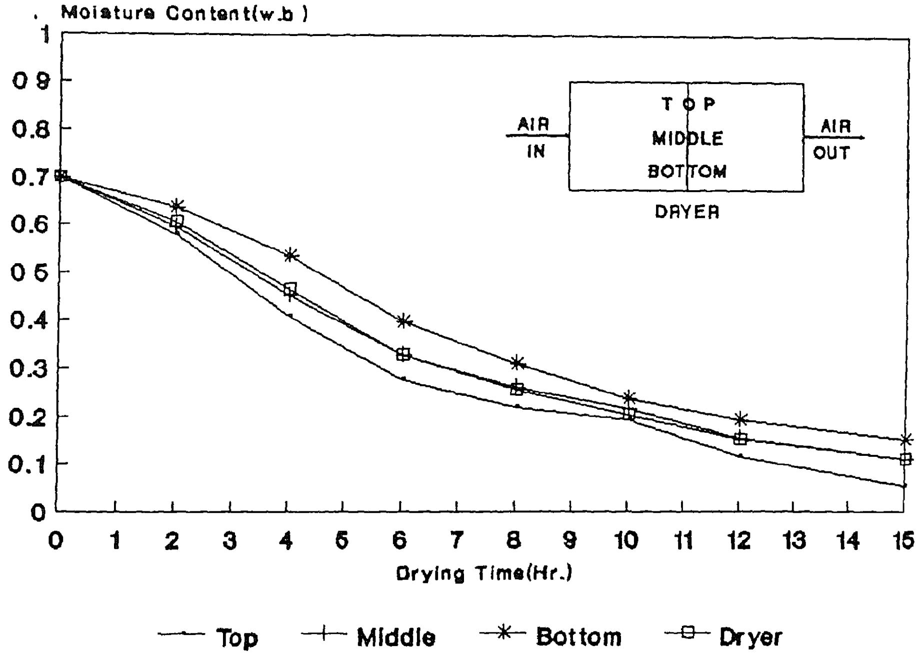


Fig. 7.29 Coffee drying: moisture content vs. time
(Date:- Jan. 1-2, 1991)

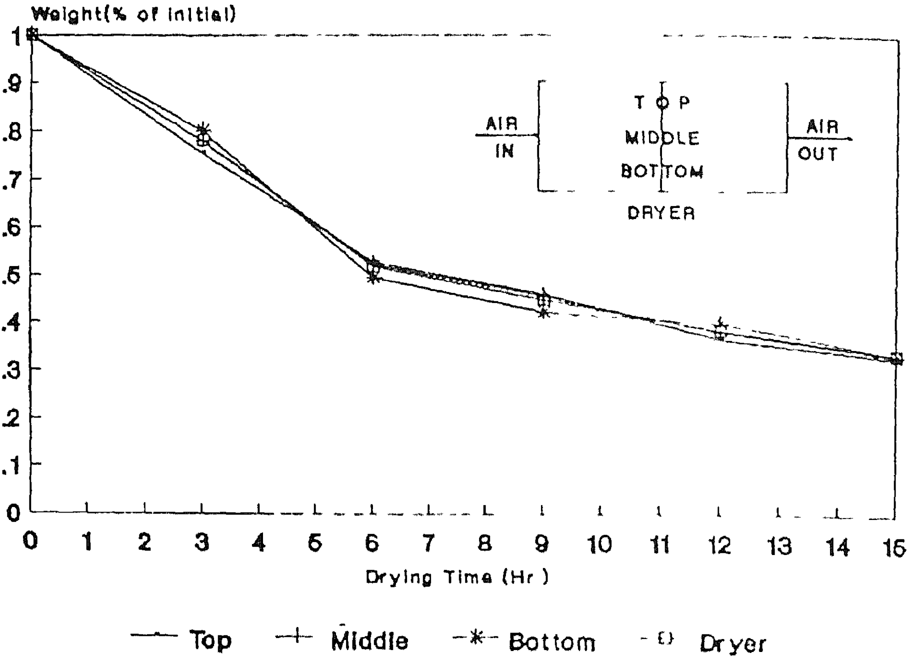


Fig. 7.30 Coffee drying: weight loss curve
(Date:- Jan 3-4, 1991)

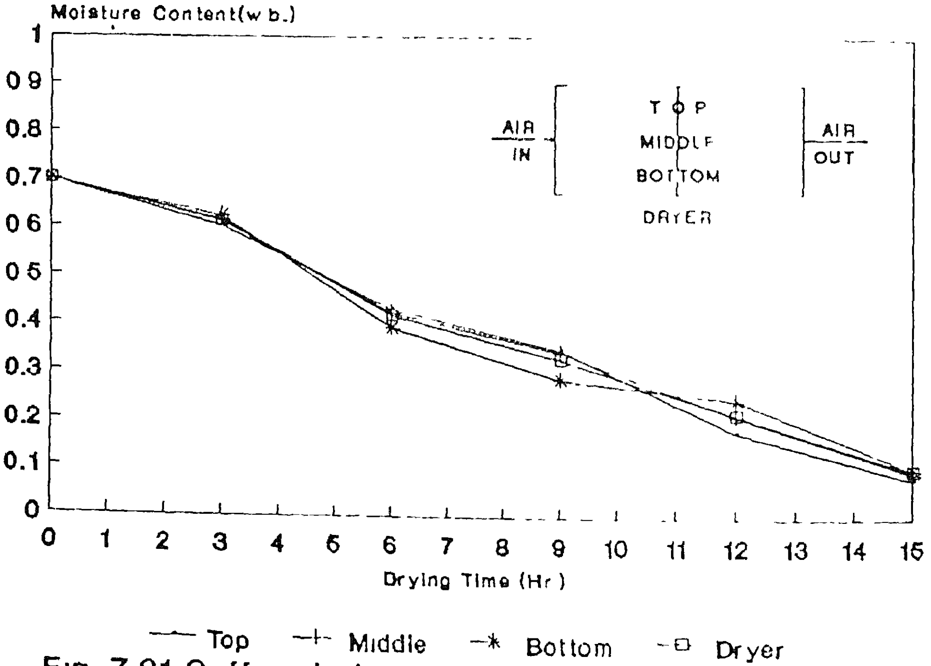


Fig. 7.31 Coffee drying: moisture content vs. time
(Date - Jan 3-4, 1991)

performance of the combined furnace and heat exchanger unit. Since the system is not utilised to its full capacity (200 kg of fresh cardamom as per theoretical performance predictions) the overall dryer efficiency was not computed. The detailed procedure to evaluate the performance of the unit is given in Annexure II.

From Table 7.1 it can be observed that the furnace operates at a efficiency of about 50-60% and plate-fin type heat exchanger with effectiveness of about 80-85% resulting in the combined thermal efficiency of furnace and heat exchanger at about 40-50%. Thus the heat exchanger developed can be seen to be operating at a very high effectiveness compared to the flue pipe

Table 7.1: Summary of performance evaluation of prototype drying unit

Date	Crop	Fuel (kg Leco)	Time (Hr)	Tain (^{o}C)	Taout (^{o}C)	Tgin (^{o}C)	Tgout (^{o}C)	Vain (m/s)	Qair (kcal)	Qfuel (kcal)'	Thermal Efficiency		
											Heat Exch-anger	Fur-nace	Comb-ined
27/28-11-90	Ca*	30 50	17.0	18 2	54 2	227 3	59.6	13.90	4953.5	12379 4	0.802	0 498	0 400
13/14-12-90	Ca	30 10	17.5	15 5	51 8	349.1	44.9	17.37	6293.6	11868 0	0 912	0 581	0.530
14/15-12-90	Ca	24 60	14 0	14 7	51 1	309 3	46 2	18.16	6614 1	12124 3	0 893	0 611	0.546
15/16-12-90	Ca	20 80	14 5	14 5	49 7	231 3	46.4	14 30	5049 8	9897 9	0 853	0 598	0 510
17/18-12-90	Ca	30 80	17 0	18 4	51 3	242 5	49.9	17.19	5623 0	12501 2	0 859	0 523	0 450
21/22-12-90	Ca	24 50	16 0	17 8	50 1	231 9	51 4	16.24	5230 6	10565 6	0 843	0 587	0 495
22/23-12-90	Ca	27 02	17 5	19 1	49 9	272 5	52 6	13.28	4071 4	10653 6	0.868	0 440	0 382
23/24-12-90	Ca	24 57	17 0	22 1	50 8	238 4	52 3	18.02	5115 4	9972 5	0 860	0.596	0 513
24/25-12-90	Ca	21 84	17.5	20 3	49 7	308 0	54 2	16.35	4776 9	8611 2	0.882	0.629	0.555
28-12-90	Co & Pe*	30 24	16 0	21 4	64 1	362 3	73.5	13.70	5670.8	13041 0	0.847	0 513	0.435
29/30-12-90	Pe	20.79	13 0	22 8	77 9	432.0	101 0	8 95	4668.1	11034 7	0.809	0 523	0.423
01/02-01-91	Co*	22.49	19 0	23 1	81.5	445.7	103 7	7.24	3978.4	8167 8	0.809	0 602	0.487
02-01-91	Pe	17 01	14 5	27 9	74 7	433 9	113.3	8 57	3781.7	8094 4	0.790	0.592	0.467
03/04-01-91	Co	28 98	19 0	20 6	76 1	441.5	104.4	8 60	4543.2	10693 2	0 801	0 530	0.425
04/05-01-91	Pe	19.74	13 0	20 4	73 3	451 7	108 7	10 74	5432.2	10477 4	0.795	0 652	0 518
09/10-01-91	Co	23 52	20 0	11 0	51 3	262 4	74 3	9.70	3933 9	8196 4	0.748	0 641	0 480
15/16-01-91	Ca	24.22	20.0	17 0	47.8	234.9	69.6	8.92	2751.6	8440 3	0.759	0 430	0 326
17-01-91	Ca	25 76	21 0	19 1	50 3	215.7	71.9	8 09	2510 4	8504 5	0 732	0 404	0 295
24-01-91	Ca	23 17	20 0	18 4	43 8	241 8	45.1	11.61	2971 4	8074 4	0 880	0 418	0 368
26-01-91	Ca	24.08	20 0	20 5	41 7	341.0	44 5	16 65	3559.3	8391.5	0.925	0 459	0 424

Note - All values are the average of data collected for one set of drying experiment

* Ca - Cardamom, Pe - Pepper, Co - Coffee

heat exchanger (operating with 11-12% effectiveness) of the conventional cardamom curing chamber thus achieving the major objective of this project.

7.8 Heating of Existing Cardamom Curing Chamber

At the end of field testing it was decided to try the prototype unit to heat the existing cardamom curing chamber. But since the second prototype unit is much smaller compared to the existing curing chamber it was not possible to do it. The present furnace of conventional system consumes approximately 1200 -1300 kg of firewood per batch which means approximately 60-65 kg/hr. This is equivalent to approximately 35 kg/hr of leco. But the furnace of the prototype unit is designed for burning rate of 4 kg/hr which is too small. Though as per performance predictions of the system the hot air available is sufficient to dry 200 kg of cardamom, the existing structure is very big. In the conventional system ground floor of the building is for flue pipe arrangement and only top half is used for loading cardamom. The gap between two layers of tray is approximately 2 feet and with total capacity of 400 kg of fresh cardamom. Hence the prototype unit was not of comparable size to heat the huge structure such as the existing cardamom curing chamber.

8. SCOPE FOR APPLICATION OF THE UNIT

During field testing of the prototype unit, cash crops such as cardamom, coffee and pepper are successfully dried. Due to the application of forced flow of hot air in the dryer, time required for crop drying is substantially reduced. The field testing of the unit indicates that faster drying using forced flow of hot air in the dryer and improving efficiency of the system using energy efficient heat exchanger (such as the one developed under this project) is possible in case of many crops such as pepper, coffee and even cardamom which is supposed to be a delicate process requiring controlled drying to maintain its green colour. The unit gives much better thermal performance of furnace and heat exchanger than the conventional flue pipe type heat exchanger. In principle the system developed here can be used for drying of different cash crops just by tuning the system to get the required air flow rate and temperature for drying a particular crop. The blowers which were operated by electric power for this field testing may appear to be the drawback of the system as the electricity supply in the hilly region of western ghats is unreliable, but diesel engines can be used to run the blower in actual use of the system in the field. Following are the major areas where the system can be used more efficiently:

(a) **Cardamom:** Cardamom cultivation is mainly small planter's activity. There are large number of cardamom estates with small area under cultivation and a few estates are having large area under cultivation. Small planters can't afford to have continuous power supply using a generator. Since cultivated area is small they don't have big curing chambers and also they have to depend on others for fuelwood supply. The drying unit developed under this project is suitable for small and medium planters (with 100-200 kg fresh cardamom capacity) as it is cheap, operates on leco coal which is available in south India and needs small structure for dryer. Faster drying allows to dry fresh batch of cardamom daily thus reducing the size of the dryer.

(b) Coffee: At present coffee is sundried in almost all estates. For sundrying of coffee it takes about 4-5 days at the estate level and further 3-4 days at the coffee curing house for parchment coffee and still higher time is required for cherry coffee. Large open space is required to spread coffee seeds for drying under sun. Also the process is labour intensive since every day the coffee has to be spread in the morning and has to be collected again in the evening. Since frequent sudden spells of showers are common during coffee harvesting season the use of this prototype unit gains more importance. Drying time, labour and space required are drastically reduced with application of this system for coffee drying.

(c) Pepper: At present pepper is also sundried like coffee. Drying of pepper under sun takes 2-3 days. The drying time can be reduced to 5-7 hrs. if the pepper is dried using this unit. The system is more useful during rainy days. Faster drying of pepper results in small required space and drying independent of the outside weather conditions.

(d) Tobacco: The type of heat exchanger used in flue curing of Virginia tobacco leaves in the conventional barn is similar to that used in the conventional cardamom curing chamber. In tobacco barns the heat exchanger used is flue pipe type having very low thermal effectiveness. The prototype unit employing the compact and efficient plate-fin heat exchanger can be used in curing of virginia tobacco leaves to dry it quickly and more efficiently.

(e) Cashew: In the case of cashew the fuel available from the shell of the cashew nut is sufficient for processing of the cashew. The heat exchanger used to supply hot air to the 'borma' for heating of cashew nuts is shell and tube type. Since the heat transfer coefficient values are very low for gaseous fluid, use of the proto-type unit employing compact plate-fin type cross flow heat exchanger will improve the effectiveness of the air heating system by providing large heat transfer area per unit volume of the heat exchanger resulting in saving of cashew shell fuel which in turn can be used for many other useful purposes.

(f) Copra: Copra drying is at present done either under sun or in the dryer developed using copra shell or electricity as fuel. The heat exchanger used in these dryers is also based on natural convection. The proto-type unit can be used to supply hot air for drying of copra under closed protected atmosphere to get good quality of dry copra. Also the capacity of the dryer can be increased with reduction in drying time.

In principle, this system can be used in many other applications where hot air is required for drying, such as fish, foam, rubber, grapes, date, etc.. Fish at present is dried in open air resulting in a poor quality of the product. Exposure to atmospheric air results in deterioration of quality of the dry fish resulting in wastage of final product. Also in coastal areas where fish drying is a major activity the availability of sunshine for long time is difficult, on contrary sudden spells of showers is a routine phenomenon which destroys the valuable product output. The same can be dried under closed atmosphere using hot air which will result in faster drying as well as better quality of the dried fish. Of course before applying the system to any application it has to be tested first and if necessary the various components has to be tuned as per the requirement of the individual application. For example use of the presently developed furnace-heat exchanger combination with energy-saving retrofits such as insulation or with advanced system such as fludised bed drying, will definitely result in a large overall efficiency.

9. FUTURE SCOPE FOR IMPROVING DRYING SYSTEM OF CASH CROPS

Here various options for improving the efficiency of drying system for various cash crops is discussed.

9.1 Biomass Gasifier System for Drying and Power Generation

Cash crop drying is an energy intensive activity. In South India, although the dependence has been on multiple sources, with the volatile increase in their prices as well as their short supply, the energy problem has assumed considerable significance. The promising sources of energy presently are firewood, coal, furnace oil, leco, diesel etc.. Firewood dominates the fuel consumption scene in plantation estates of south India due to the rapid rise in cost of production for fuels other than firewood. High costs apart from the shortage and non-availability have adversely affected the industry. Likewise the shortage of coal at pit-head or wagon shortage for transport of coal to the consuming centers in the south have made coal supply unreliable. Supply of electricity from departmental sources being inadequate, tea factories have been compelled to adopt self generation which is a costly process.

The need for according priority for the conservation and better use of energy can hardly be overemphasized. Drying department utilizes approximately 75 to 80 per cent of the total energy requirement. Although the present air heating system using firewood .as fuel are inefficient giving rise to high specific fuel consumption (kg of fuel consumed per kg of dry product) values the popular use of firewood is attributable to the following reasons:

1. Compared with other fuels, firewood is relatively easy to obtain from local sources and some of them are still left with marginal areas of man made forests which ensure regular supply of fuel wood.
2. Fuel wood is a cheap source of energy compared to alternatives such as oil, leco, coal.
3. It is a renewable source of energy which could be generated within the estate. About 20 per cent of the tea area would be required for generating energy wood through systematic rotational planting.

The energy situation in the plantation industry thus calls for a strategy and long term policy to overcome the present impediments and provide for future requirements. The important ingredients visualized for such a policy are:

1. Estimation of future energy requirements and evolving policies to meet future needs.
2. Efficient utilization of applied energy resources already in use in the industry.
3. Application of renewable energy sources such as fuel wood, biomass, agriculture waste etc.
4. Application of new/non-conventional energy sources with a view of improving efficiency and reducing costs.

In the gasifier system the fuel in the form of chopped firewood or briquettes of any biomass (such as coir pith, coffee husk, etc.) is gasified (i.e. burned under controlled insufficient air supply) to obtain producer gas. This combustible gas produced in the gasifier undergoes the process of cleaning and cooling, to remove tar and dust content to an acceptable level. This gas is then burned with sufficient amount of excess air in a burner to obtain the required temperature and the resulting hot air-gas mixture can be directly used for drying. Thus the gasifier system can, in principle eliminate the heat exchanger in conventional system.

Power cut is a regular phenomenon in hilly areas of the Nilgiris where majority of tea factories and other plantation estates are located. So the industry has to go for diesel generator sets for regular power supply. Gasifier application can also be extended for power generation making the complete system independent without relying on the main commercial source of energy such as coal and electricity. For this purpose the diesel engine of the generator is operated on dual fuel mode (i.e. both diesel and producer gas are supplied to engine) resulting in about 65-70% diesel replacement thus needing only 30-35% diesel.

Figure 9.1 shows the flow diagram of the biomass gasifier system which can be used for drying or power generation or both simultaneously.

Since heat exchanger is absent in the gasifier based drying system the overall efficiency of the drying process will be obviously higher than the present drying system resulting in large fuel savings. The system application is extendable to power generation which gives about 65%-70% diesel replacement in diesel generators, thus saving large amounts of diesel. Thus

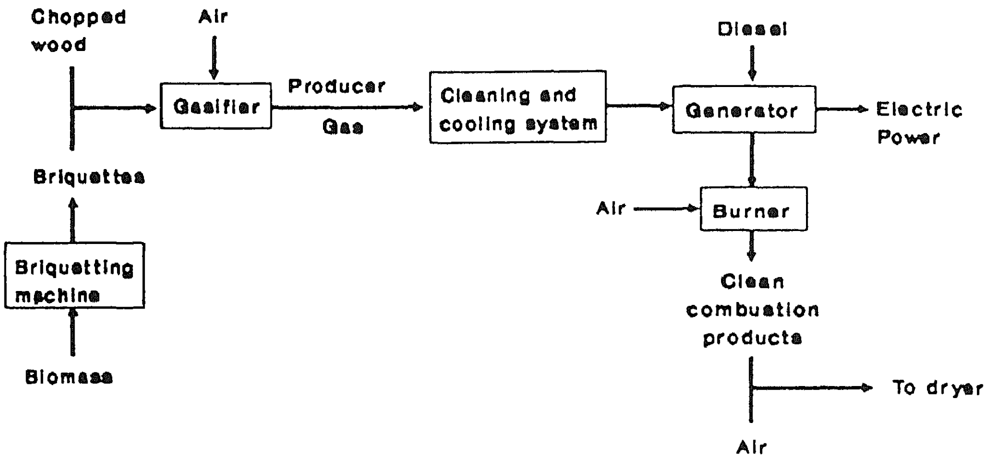


Fig. 9.1 Biomass gasifier based drying / power generating system

biomass gasifier based drying systems can give benefit and so return of the investment incurred in it by two ways:

(a) Fuel wood saving in drying process

(b) Diesel saving in power generation

Such a system is very useful specially for tea industry where there is a large demand for uninterrupted supply of thermal and electrical energy. In tea estates it is possible to reserve portion of the land for forestration to ensure continuous supply of firewood.

9.2 Improving Existing Conventional Curing Chambers

The conventional curing chambers either for cardamom or for tobacco, is a big room through which flue pipes are laid down for air heating. This is a huge structure and the planters are hesitant to switch over to a completely new drying system. Therefore if efforts are directed towards the improvement of conventional curing chambers, many planters may come forward to implement the modifications suggested to improve the efficiency of the existing curing chamber. This approach may gain wider acceptability among planters since existing curing chambers can be used as it is.

In order to improve the efficiency of the curing chamber following options can be considered.

(i) Providing black paint on the flue pipe to improve the heat radiated by the flue pipe

(ii) Providing fins on the flue pipe in order to increase the heat transfer area

(iii) To provide insulation to the walls to prevent loss of heat through it. Providing insulation inside may be more effective since the absorption of heat by the walls would then be lower.

(iv) Providing radiation shield between flue pipe and wall structure. This may help in utilising radiant heat to heat the air rather than wasting it if it falls on the wall structure where it will get absorbed and will not be given back to air.

(v) Providing small annulus type structure around flue pipe and circulating room are over the flue pipe through the annulus with the help of small blower which may increase the heat transfer coefficient on air side.

Though all these options improve the heat transfer the options (iii) to (v) seem to be more effective since these improve the heat gained by the air rather than just throwing out more heat from the flue pipe. Of course all these options have to be tested for their relative effectiveness.

Similarly these options can also be applied for improving the thermal effectiveness of tobacco curing barns.

9.3 Suggestions for the Second Phase of the Project

After achieving the successful drying of cash crops such as cardamom, coffee and pepper using an energy efficient drying system developed under this project it will be better to demonstrate this system to the planters. Hence it is suggested that in the second phase of this project, which will be totally field oriented, a few systems should be installed at various estates and their performance should be monitored for a season or two. This will help in developing confidence among planters about the system so that in future they will come forward for utilising the improved system.

For the successful completion of the second phase it is envisaged that UPASI and some Estates should be involved to work together. TERI can provide technical design input of the drying system, and an institute like UPASI can organise the field testing of the units in co-operation with field estates.

10. CONCLUSIONS

A prototype drying system for faster and efficient drying of cash crops has been developed. The system consists of a furnace, a heat exchanger, a cabinet tray dryer and two blowers. The heart of the system is a compact plate-fin type cross flow (both the fluids unmixed) heat exchanger operating at a high heat transfer effectiveness. The use of plate-fins provide more heat transfer area to overcome the low heat transfer values for gaseous fluids. The fabrication method is made simpler without compromising on the performance. A simple device is developed to make the fabrication of the plate-fin easy so as to make it possible at local workshops in remote hilly areas of western ghats where the cultivation of cash crop is concentrated. Furnace is designed for continuous operation using leco as fuel which is the available form of coal in south India. Forced flow of hot air is used in the cabinet tray dryer to make the drying process faster. Blower which was operated on electricity can be coupled to a diesel engine in order to make the system independent from external supply of electricity which is highly unreliable in this region.

Cardamom, coffee and pepper had been successfully dried in the field using the proto-type drying unit. The quality of the final dried product is satisfactory and comparable to that of conventionally dried product. Time required for drying is substantially reduced. In case of cardamom the drying time is reduced from 18-20 hrs to 14-15 hrs hrs. Coffee and pepper is dried in 7-10 hrs and 15-17 hrs as against 3-4 days and 4-5 days required under present sundrying method. Significant improvement in the combined thermal performance of furnace and heat exchanger is achieved.

The overall system concept and configuration has been achieved in which several devices performing different functions had been assembled in an optimal fashion. The prototype drying unit developed has a significant potential for drying of several cash crops and other drying applications. The heat exchanger developed can be used for efficient heat recovery in many industrial processes.

NOMENCLTURE

A	Heat transfer area of heat exchanger
A_a	Area of cross section for air flow
A_g	Area of cross section for gas flow
C_a	Heat capacity rate of air
C_g	Heat capacity rate of gas
c_{pa}	Specific heat of air
c_{pg}	Specific heat of gas
EAF	Excess air factor
h_a	Heat transfer coefficient on air side
h_g	heat transfer coefficient on gas side
k_g	Thermal conductivity of gas
L	Size of heat exchanger
m_a	Mass flow rate of air
M_f	Final moisture content of crop (w.b.)
m_f	Burning rate of fuel
m_g	Mass flow rate of gas
M_i	Initial moisture content of crop (w.b.)
N	Number of transfer unit
Nu	Nesselt number
Pr	Prandtle number
R	Heat capacity rate ratio of two streams
Re	Reynolds number
$T_{a\ in}$	Inlet air temperature
$T_{a\ out}$	Outlet air temperature
T_d	Drying time
$T_{g\ in}$	Inlet gas temperature
$T_{g\ out}$	Outlet gas temperature

U	Overall heat transfer coefficient
V_a	Average air velocity
V_g	Average gas velocity
W	Drier capacity
W_f	Specific humidity of drier outlet air
W_i	Specific humidity of drier inlet air
E	Effectiveness of heat exchanger
λ	Calorific value of fuel
μ_g	Viscosity of gas
η	Fin efficiency
η_f	Furnace efficiency
ρ_a	Air density
ρ_g	Gas density

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ANNEXURE I

LIST OF RESEARCH INSTITUTES AND ESTATES/CURING HOUSES VISITED DURING THE SURVEY IN SOUTH INDIA

[A] RESEARCH INSTITUTES

1. University of Agricultural Sciences, Bangalore (Karnataka).
2. Central Coffee Research Institute, Balehonnur (Karnataka).
3. Regional Research Station, University of Agricultural Sciences, Mudigere (Karnataka).
4. Central Plantation Crops Research Institute, Kasaragod (Kerala).
5. Central Food Technological Research Institute, Mysore (Karnataka).
6. UPASI Tea Research Institute, Valparai (Tamil Nadu).
7. UPASI Coonnoor (Tamil Nadu).
8. School of Energy, Madurai Kamaraj University, Madurai (Tamil Nadu).
9. Cardamom Research Centre, Pambadumpara (Kerala).
10. Indian Cardamom Research Institute, Myladumpara (Kerala).
11. UPASI, Vandiperiyar (Kerala).
12. Kerala State Cashew Development Corporation Ltd., Quilon (Kerala).
13. Rubber Board Development Division, Cochin (Kerala).
14. Central Tobacco Research Institute, Rajahmundry (Andhra Pradesh).

[B] ESTATES/CURING HOUSES

Cardamom

1. Vellimale Estate, Vandanmettu (Kerala).
2. Lakshmi Vilas Estate, Vandanmettu (Kerala).
3. Kylaspara Estate, Kylasnadu (Kerala).
4. Plakkad Estate, Vandiperiyar (Kerala).

5. Kudukarnam Estate, Peermedu (Kerala).

6. Pambnar Estate, RBT Group, Pambnar (Kerala).

7. Arnakal Estate, AVT Group, Vandiperiyar (Kerala).

8. Winderemere Estate, Pothamedu (Kerala).

9. Manalil Estate, Pallivasal (Kerala).

10. Masjish Gardens, Pothamedu (Kerala).

Cashew

11. Lakshmi and Co. Cashew Factory No. 44, Quilon (Kerala).

12. Century and Co. Cashew Factory No. 51, Quilon (Kerala).

13. Cashew Processing Factory, Achal Industrial Estate, Mangalore (Karnataka).

Coffee

14. Mysore Coffee Curing Works Pvt. Ltd., Chikmagalur (Karnataka).

15. Chikmagalur Coffee Curing Works, Chikmagalur (Karnataka).

16. Jayanthi Coffee Works Ltd., Chikmagalur (Karnataka).

17. Lalithadri Estate, Hosepeth (Karnataka).

18. Kothari Industrial Corporation Ltd., Hassan (Karnataka).

19. Ganga Coffee Curing Works Pvt. Ltd., Hassan (Karnataka).

20. Hassan Coffee Curing Works, Hassan (Karnataka).

Tea

21. Peria Karmalai Tea and Produce Co. Ltd., Coimbatore (Tamil Nadu).

22. INDCO Tea Factory, Ithelar, Ooty (Tamil Nadu).

23. INDCO Serve, Coonnoor (Tamil Nadu).

24. INDCO Tea Factory, Koribetta (Tamil Nadu).

25. INDCO Tea Factory, Kotagiri (Tamil Nadu).

26. The Pandian Engineering Industries, Kotagiri (Tamil Nadu).

27. Arnakal Tea Factory, AVT Group, Vandiperiyar (Kerala).

28. Pallivasal Tea Factory of Tata Tea Ltd., Pallivasal (Kerala).

Tobacco

29. Katheru Farm, Rajahmundry (Andhra Pradesh).

ANNEXURE - II

PROCEDURE FOR PERFORMANCE EVALUATION OF PROTOTYPE DRYING UNIT

In this annexure detailed procedure to evaluate the combined performance of furnace and heat exchanger is given. The summary of the data collected during field testing of the unit for drying cash crops like cardamom, pepper and coffee is given in Table 8.1. Here a detailed procedure of performance evaluation for the experiment carried out on November 27-28, 1990 for cardamom drying is described.

The average values of the data collected for the experiment from Table 8.1 are:

Total duration of operation = 17.0 hrs
Total Leco consumed = 30.50 kg

Heat exchanger,

Air inlet temperature ($T_{a,in}$) = 18.2 ^{o}C
Air outlet temperature ($T_{a,out}$) = 54.2 ^{o}C
Gas inlet temperature ($T_{g,in}$) 227.3 ^{o}C
Gas outlet temperature ($T_{g,out}$) = 59.6 ^{o}C
Velocity of air in duct (V_{air}) = 13.92 m/s
Flow area of the duct (A_{duct}) = 0.01 m^2

where A_{duct} is the area of the inlet duct where velocity of the ambient air flowing into the heat exchanger is measured with the help of vane type anemometer.

Air and Gas Properties:

Density of air at ambient temperature,

$$\rho_{air} = 1.14 \text{ kg/m}^3$$

Average air temperature

$$T_{a,avg} = (T_{a,in} + T_{a,out})/2$$
$$= (18.2 + 54.2)/2$$
$$= 36.2 \ ^{o}C$$

Average gas temperature,

$$T_{g,avg} = (T_{g,in} + T_{g,out})/2$$
$$= (227.3 + 59.6)/2$$
$$= 143.5 \ ^{o}C$$

Specific heat of air (c_{pa}) $= 0.241$ kcal/kg^{o}C

Specific heat of gas (c_{pg}) $= 0.259$ kcal/kg^{o}C

Mass flow rate of air (m_a) $= air \cdot A_{air} \cdot V_{air}$

$$= 1.14 \times 0.01 \times 13.9$$
$$= 0.1586 \text{ kg/sec}$$
$$= 570.94 \text{ kg/hr}$$

Heat gained by the air,

$$Q_{air} = m_a \cdot c_{pa} \cdot (T_{a,out} - T_{a,in})$$
$$= 570.94 \times 0.241 \times (54.2-18.2)$$
$$= 4953.52 \text{ kcal/hr}$$

Applying energy balance equation to the heat exchanger,

$$m_a \cdot c_a \cdot (T_{a,out} - T_{a,in}) = ma.cpg.(T_{g,in} - T_{g,out})$$

the mass flow rate of gas can be calculated as,

$$m_g = \frac{Q_{air}}{c_g \cdot (T_{g,in} - T_{g,out})}$$

$$= \frac{4953.52}{0.259 \times (227.3-59.6)}$$

$$= 114.122 \text{ kg/hr}$$

Therefore,

capacity rate of air (C_a) $= m_a \cdot c_a$

$= 570.94 \times 0.241$

$= 137.5976$ kcal/hr°C

capacity rate of gas (C_g) $= m_g \cdot c_g$

$= 114.122 \times 0.259$

$= 29.54$ kcal/hr°C

Minimum capacity rate (C_{min}) $= C_g$

$= 29.54$ kcal/hr°C

Heat transfer effectiveness of heat exchanger is defined as actual heat transfer to that of maximum possible heat that can be transferred.

$$E = \frac{Q_{air}}{C_{min} \cdot (T_{g,in} - T_{a,in})}$$

$$= \frac{4953.52}{29.54 \times (227.3-18.2)}$$

$$= 0.802 = 80.2\ \%$$

Combined furnace and heat exchanger efficiency is defined as the ratio of the useful heat gained by air to the heat input to the furnace in the form of calorific value of the fuel.

$$\text{Combined efficiency} = \frac{Q_{air}}{Q_{fuel}}$$

where,

$$Q_{fuel} = (\text{fuel consumed x calorific value})/\text{time}$$

$$= (30.50 \text{ x } 6900)/17.0$$

$$= 12379.4 \text{ kcal/hr}$$

therefore,

$$\text{Combined efficiency} = \frac{4953.52}{12379.40}$$

$$= 0.400 = 40.0 \%$$

Therefore now the furnace efficiency can be calculated from the the relation,

$$\text{Furnace efficiency} = \frac{\text{Combined efficiency}}{\text{Heat exchanger effectiveness}}$$

$$= \frac{0.400}{0.802}$$

$$= 0.4989 = 49.89 \%$$